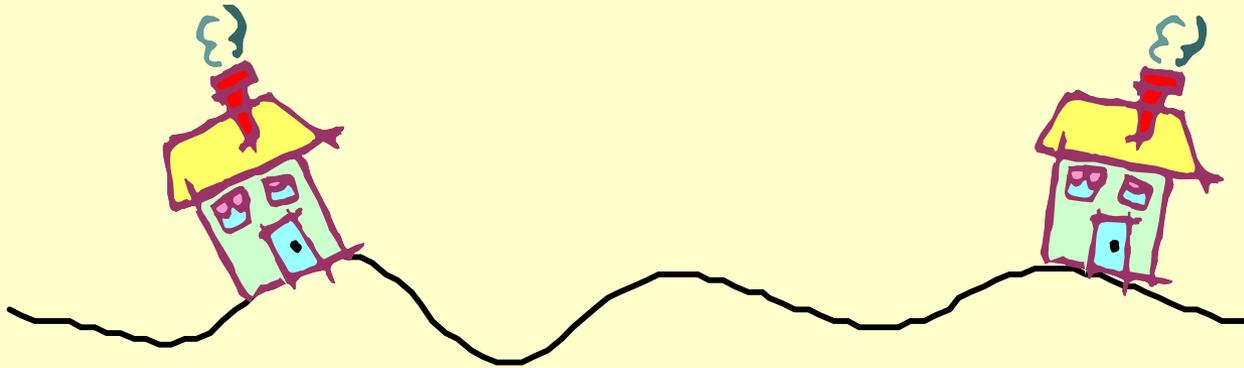

Controlling the Adverse Effects of Blasting



This blaster-training module was put together, under contract, with Federal funds provided by the Office of Technology Transfer, Western Regional Office, Office of Surface Mining, U.S. Department of the Interior, located in Denver, Colorado.

The module is an example of the technical assistance the Federal government furnishes States to assist them in meeting the requirements of the Surface Mining Control and Reclamation Act of 1977, upon which their State surface coal-mine regulating programs are based. In particular, the module was requested and will be used by the Sheridan District Office, Wyoming Department of Environmental Quality, Land Quality Division.

A word of caution: please note that **this module is not intended to stand alone, nor is it a self-training type module.** Rather, **the information the module provides MUST BE SUPPLEMENTED** by information given by a certified blasting instructor.

DISCLAIMER

The technologies described in the module are for information purposes only. The mention herein, of the technologies, companies, or any brand names, does not constitute endorsement by the U.S. Department of the Interior's Office of Surface Mining.

Controlling the Adverse Effects of Blasting

This module addresses the control of offsite impacts that result from blasting, namely:

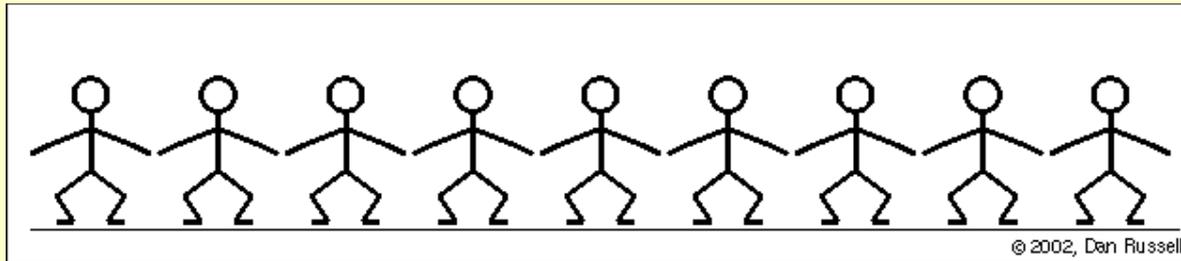
- vibrations,
- airblast, and
- flyrock.

Much of the information in the module is derived from the Surface Mining Control and Reclamation Act of 1977 (SMCRA). The performance standards apply to all surface coal mines. Similar standards have been adopted on some State and local levels and applied to non-coal blasting operations such as quarrying and construction.



Part I: Ground Vibrations, Airblast, and Flyrock

Explosive energy is used to break rock. However, the use of this energy is not 100-percent efficient. Some of the energy escapes into the atmosphere to generate **airblast or air vibrations**. Some of the energy also leaves the blast site through the surface soil and bedrock in the form of **ground vibrations**.



Both air and ground vibrations create waves that disturb the material in which they travel. When these waves encounter a structure, they cause it to shake. Ground vibrations enter the house through the basement and airblast enters the house through the walls and roof.

Airblast may be audible (noise) or in-audible (concussion). When outside a house the blast may be heard because of the noise, however noise has little impact on the structure. The concussion wave causes the structure to shake and rattles objects hanging on walls or sitting on shelves. This “interior noise” will alarm and startle people living in the house.

Flyrock is debris ejected from the blast site that is traveling through the air or along the ground. Flyrock the single most dangerous adverse effect that can cause property damage and personal injury or death.

Blasting Impacts on Structures

Both above-ground and below-ground structures are susceptible to vibration impacts. Structures can include onsite mine offices and buildings, as well as offsite residences, schools, churches, power-transmission lines, and buried pipelines. Some of these structures may include historic or cultural features sensitive to even low levels of vibrations.

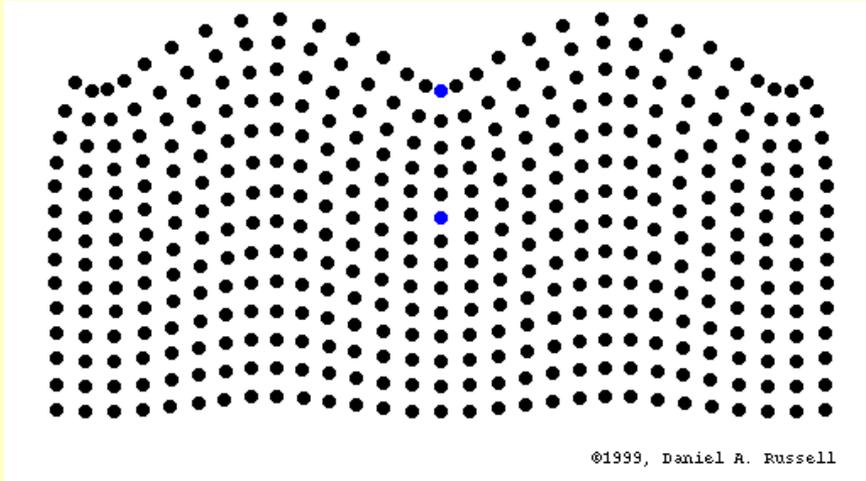


It is important to understand:

1. the causes of ground vibrations and airblast, and
2. what practices can be followed to control and minimize the adverse effects

Ground Vibrations

Ground vibrations propagate away from a blast site as Rayleigh (or surface) waves. These waves form a disturbance in the ground that displaces particles of soil or rock as they pass by. Particle motions are quite complicated. At the ground surface (free boundary), measured particle motions have the greatest displacements, and displacements decrease with depth (see the illustration below). At a depth of between 20 to 50 feet below ground surface, particle displacements are barely detectable. Structures that are well coupled to the ground tend to move with this motion; structures buried in the ground are less affected by surface motions.



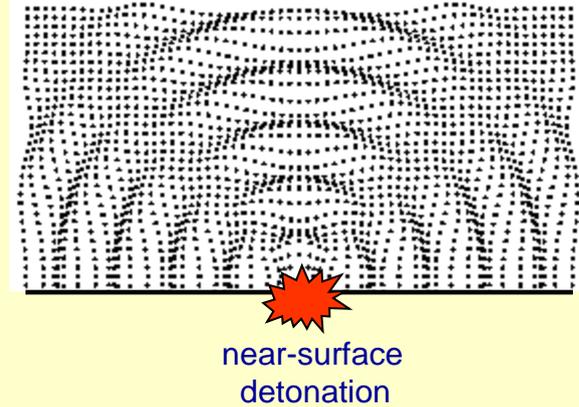
Ground vibrations are measured in terms of **particle velocity** and are reported in inches per second (ips) or the speed at which a particle of soil or rock moves.

At typical blasting distances from residential structures, the ground only moves with displacements equal to the thickness of a piece of writing paper. In terms of displacement, this equates to hundredths of an inch; visually, such movement cannot be detected.

Airblast

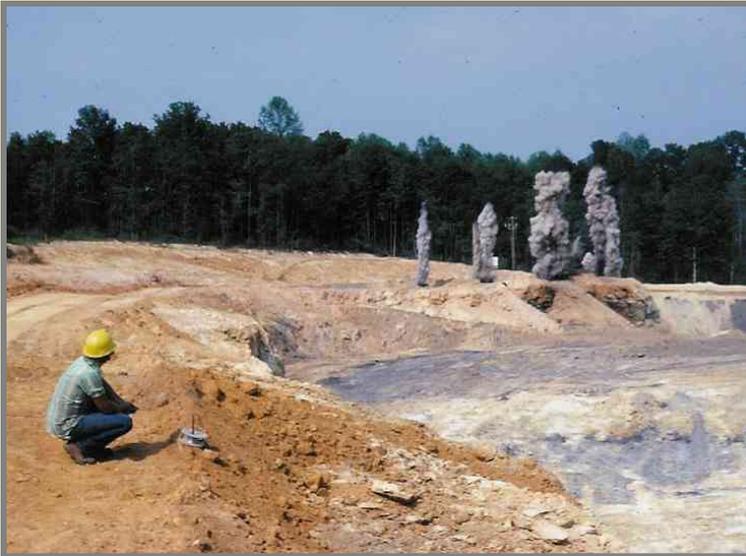
Airblast is measured as a pressure in pounds per square inch (psi) and is often reported in terms of **decibels (dB)**.

Airblast is a pressure wave that that may be audible or in-audible. Elevated airblast levels are generated when explosive energy in the form gases escape from the detonating blast holes. Energy escapes either through the top stemming or through fractures in the rock along the face or at the ground surface.



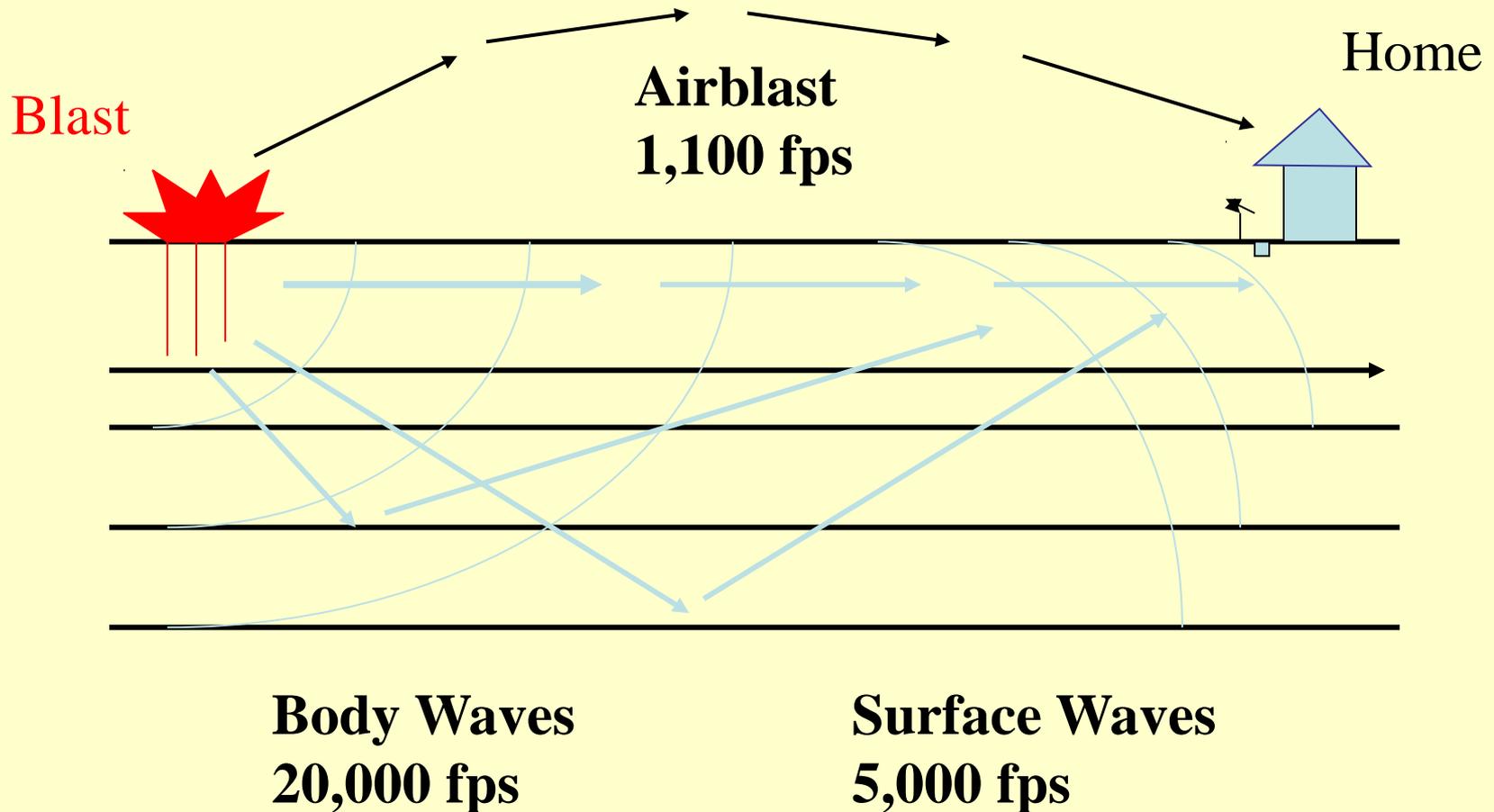
Airblast radiates outward from the blast site in all directions and can travel long distances. Sound waves travel much slower (1,100 ft/s) than ground vibrations (about 5,000 – 20,000 ft/s) . Hence, airblast arrives at offsite structures later than do ground vibrations.

Both ground vibrations and airblast cause structures to shake structures. Occupants in structures that are located far from a blast may experience shaking from vibration and airblast as two separate, closely spaced events. This can be particularly bothersome, as it prolongs the duration of structure shaking and leads the property owner to think that two separate blasts occurred.



Vibration Energy

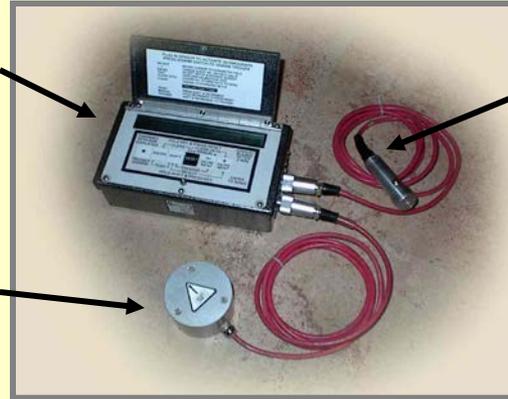
Blast vibrations travel away from a blast in all directions. At 5,000 to 25,000 feet per second, ground vibrations for all practical purposes arrive immediately at the home at the detonation of the first hole. Airblast travels much slower at 1,100 feet per second.



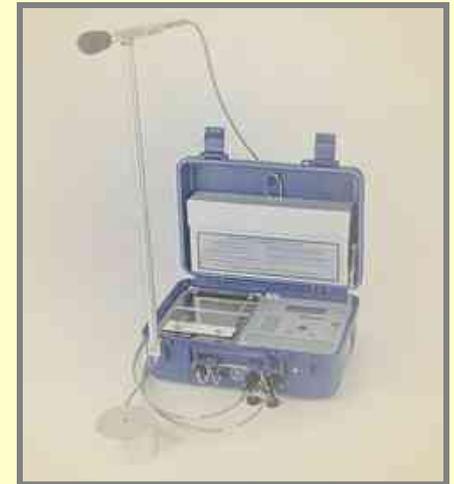
Blasting Seismographs

Ground and air vibrations are measured using a **blasting seismograph**. The components of a seismograph include:

- a seismograph for the collection and storage of vibration data.
- a geophone or ground vibration sensor

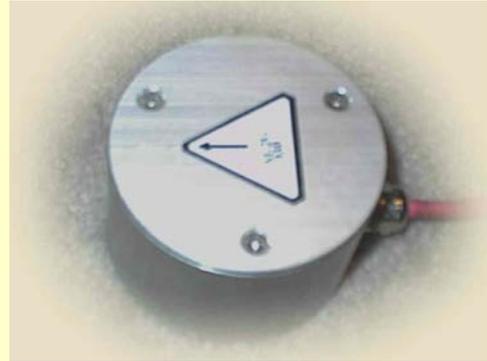
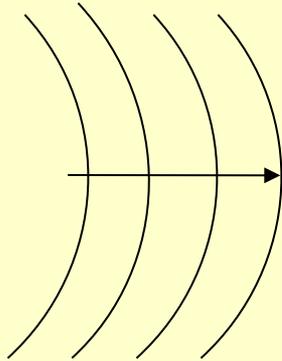


- a microphone or airblast sensor.

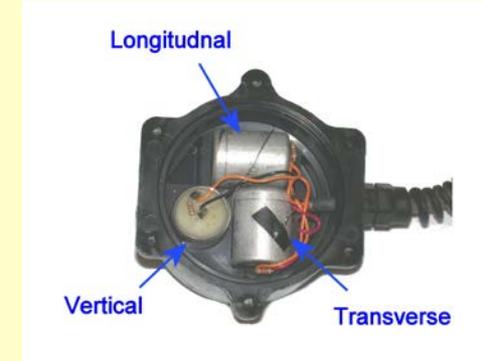


Ground Vibration Sensors

*Incoming
blast wave*



*Geophone housing (the
arrow designates
Longitudinal)*

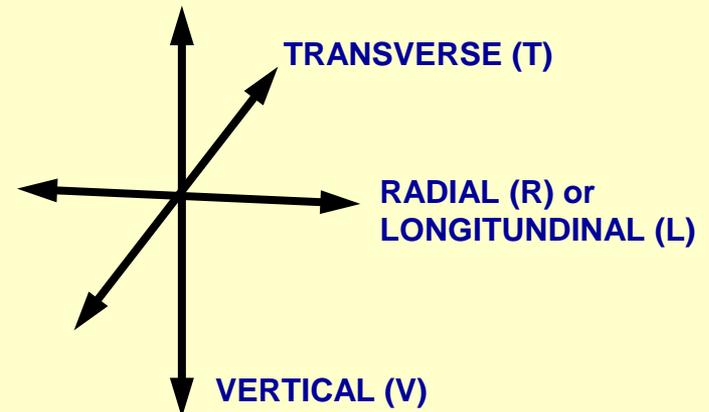


*Inside housing showing
transducer orientations*

Tri-axial geophones contain three mutually perpendicular velocity transducers. These transducers move and record ground vibrations in three directions:

- *vertical*, or perpendicular to the ground surface,
- *longitudinal or radial*, or in the direction of the incoming wave, and
- *transverse*, or perpendicular to the incoming wave.

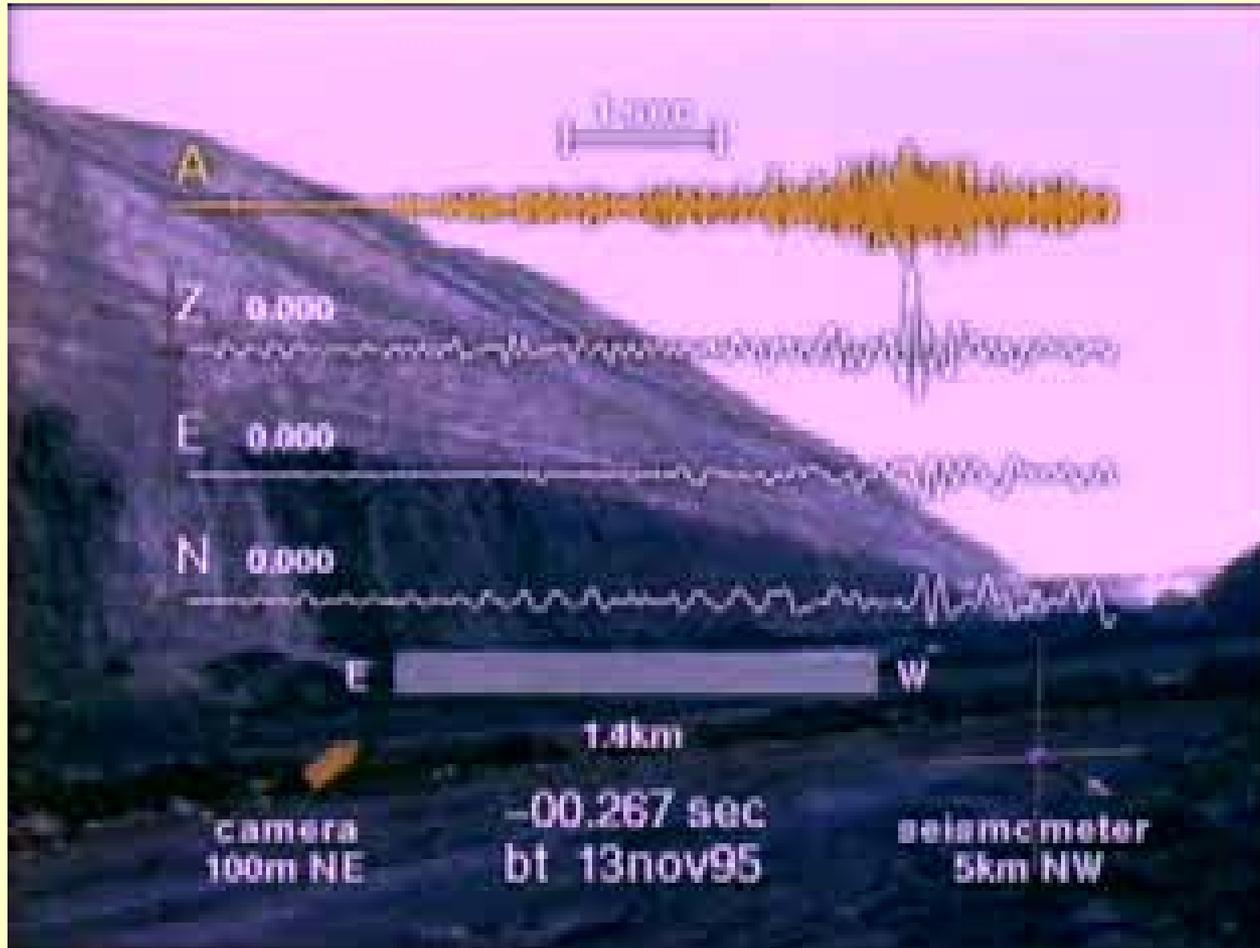
These directions of ground vibration are often referred to as V, T, and R (or L, longitudinal).



Vibrations Measurements

When excited, the ground surface moves randomly about its resting place in 3-D space. Measurements occur in the component directions (L,T, V) and are recorded as time histories of motion.

Click on the figure below to observe how a particle of soil moves in response to a large surface blast. The 3-D motion is shown in the lower right and the component motion (time history) is shown in the middle (E, N, and Z). Note what happens when 40 holes sympathetically detonate.



Note: Once the ground vibration has passed a given particle of soil, the particle comes to rest at exactly at the position it started.

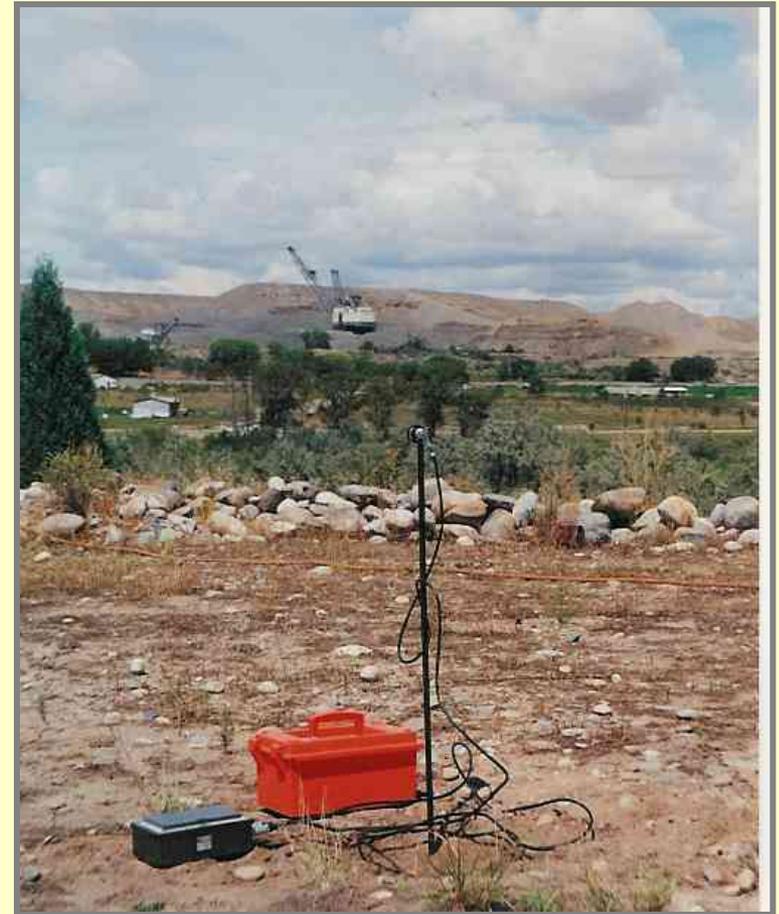
There is *no permanent displacement of the ground* after the vibration event. Click on the image again to watch the particle return to the original position.

Proper Use of Blasting Seismographs

Blasting seismographs are deployed in the field to record the levels of both blast-induced ground vibration and airblast. Accuracy of the recordings is essential. Accordingly, the International Society for Explosives Engineers (ISEE) has developed guidelines to define the user's responsibilities when deploying seismographs in the field. The ISEE *Field Practice Guidelines for Blasting Seismographs* can be found at www.isee.org.

General guidelines in this publication give parameters for:

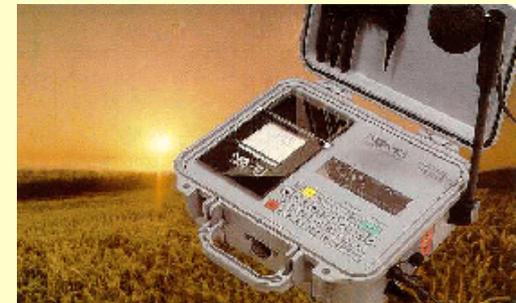
- Geophone and microphone placement (outside—never inside—a structure requiring seismographic monitoring);
- Geophone coupling to the ground (burying the geophone 4 to 6 inches under the ground surface); and
- Seismograph settings, including:
 - Maximum data range;
 - Sampling rate;
 - Total record length to capture airblast; and
 - Lowest trigger levels.



ISEE FIELD PRACTICE GUIDELINES FOR BLASTING SEISMOGRAPHS

The field practice recommendations are intended to serve as general guidelines, and cannot describe all types of field conditions. It is incumbent on the operator to evaluate these conditions and to obtain good coupling between monitoring instrument and the surface to be monitored. In all cases, the operator should describe the field conditions and setup procedures in the permanent record of each blast.

Seismographs are used to establish compliance with regulations and evaluate explosive performance. Laws and regulations have been established to prevent damage to property and injury to people. The disposition of the rules is strongly dependant on the reliability and accuracy of ground vibration and airblast data. In terms of explosive performance the same holds true. One goal of the ISEE Blast Vibrations and Seismograph Section is to ensure reliable and consistent recording of ground vibrations and air blasts between all blasting seismographs.



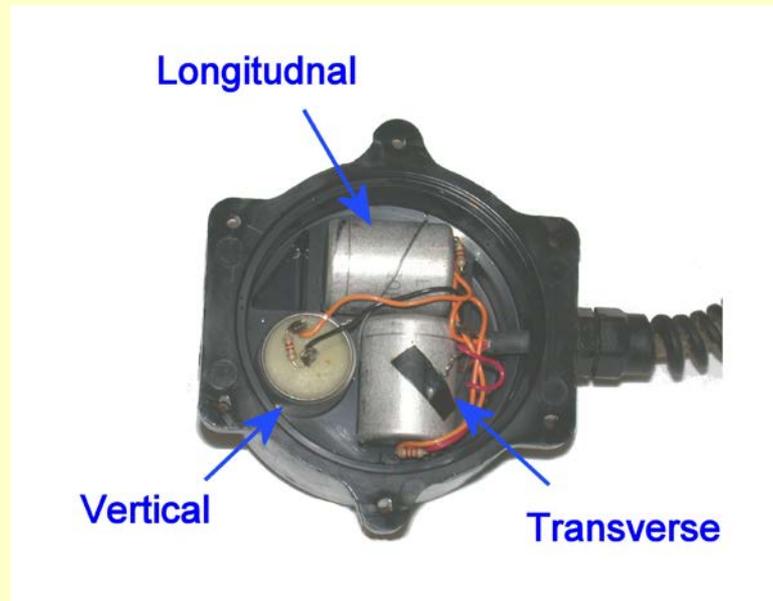
Proper Use of Blasting Seismographs

PARTS OF A BLASTING SEISMOGRAPH

Sensor



L, T, V Components



Display



Microphone





General Guidelines

Seismographs are deployed in the field to record the levels of blast-induced ground vibration and airblast. Accuracy of the recordings is essential. These guidelines define the user's responsibilities when deploying seismographs in the field.

Read the instruction manual. Every seismograph comes with an instruction manual. Users are responsible for reading the appropriate sections before monitoring a blast.



General Guidelines

Seismograph calibration. Annual calibration of the seismograph is recommended.



Keep proper records. A seismograph user's log should note: the user's name, date, time, place and other pertinent data.

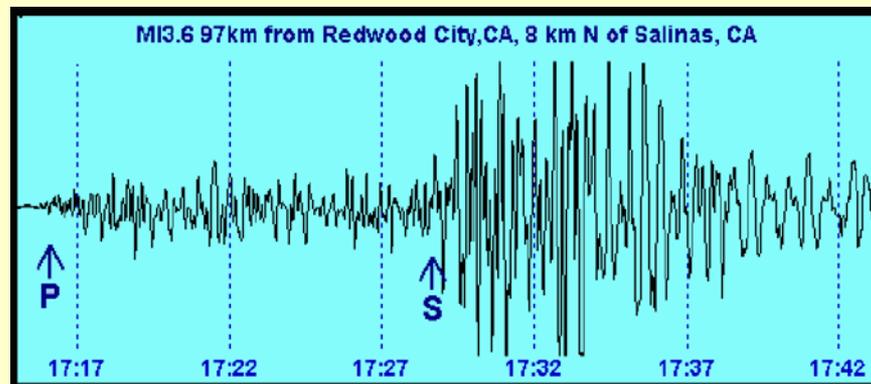
Seismograph Log KQQ serial number 2230

Entry	Set up Date	Time	Location	Operator	Break down Date	Time	Lat / Lon
1	12/12/2003	11:00	P.A.P. Garage 2213 Hwy 1002 Cox Creek, KY	Jim Cruiser	12/24/2003	16:30	37° 64.536' 85° 34.430'
2	1/12/2004	9:00	Samuel's Field Hwy 62 Bardstown, KY	B. Boyd	2/12/2004	14:45	37° 48.946' 85° 29.938'
3	2/2/2004	14:15	B12 job #21 Clark, IN	Jim Crusier	2/2/2004	15:00	38° 21.940' 85° 44.30'

General Guidelines

Record the blast. When seismographs are deployed in the field, the time spent deploying the unit justifies recording an event. As practical, set the trigger levels low enough to record each blast.

Record the full waveform. It is not recommended that the continuous recording option available on many seismographs be used for monitoring blast generated vibrations.



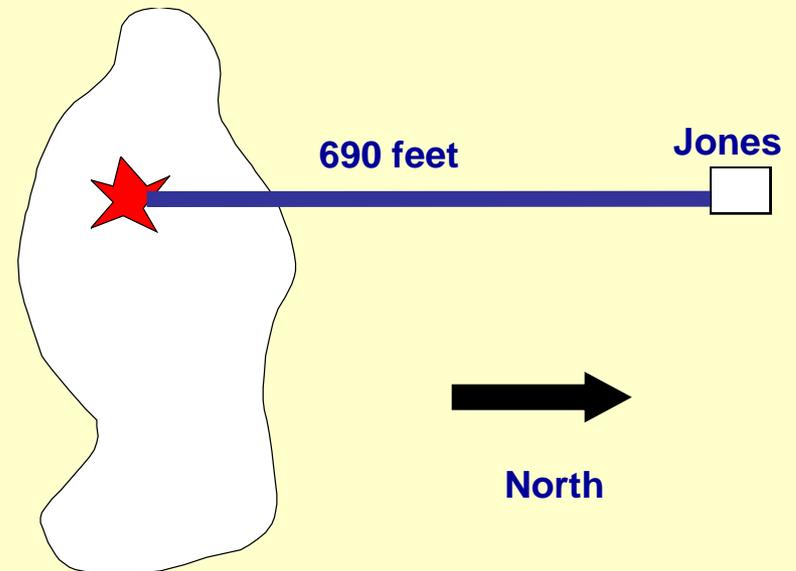
General Guidelines

Document the location of the seismograph. This includes the name of the structure and where the seismograph was placed on the property relative to the structure. Any person should be able to locate and identify the exact monitoring location at a future date.

- Full name & 911 address
- Setup time & date



Know and record the distance to the blast. The horizontal distance from the seismograph to the blast should be known to at least two significant digits. For example, a blast within 1000 feet would be measured to the nearest tens of feet and a blast within 10,000 feet would be measured to the nearest hundreds of feet. Where elevation changes exceed 2.5h:1v, slant distances or true distance should be used.



General Guidelines

Know the data processing time of the seismograph. Some units take up to 5 minutes to process and print data. If another blast occurs within this time the second blast may be missed.

Know the memory or record capacity of the seismograph. Enough memory must be available to store the event. The full waveform should be saved for future reference in either digital or analog form.

•None?

•20 seconds?

•1 Minute?

•5 Minutes?



General Guidelines

Know the nature of the report that is required. For example, provide a hard copy in the field, keep digital data as a permanent record or both. If an event is to be printed in the field, a printer with paper is needed.

Secure cables. Suspended or freely moving cables from the wind or other extraneous sources, can produce false triggers due to microphonics.

PPV Wave Form

Digital Data

Frequency?

Zero Crossing

Fast Fourier Transform

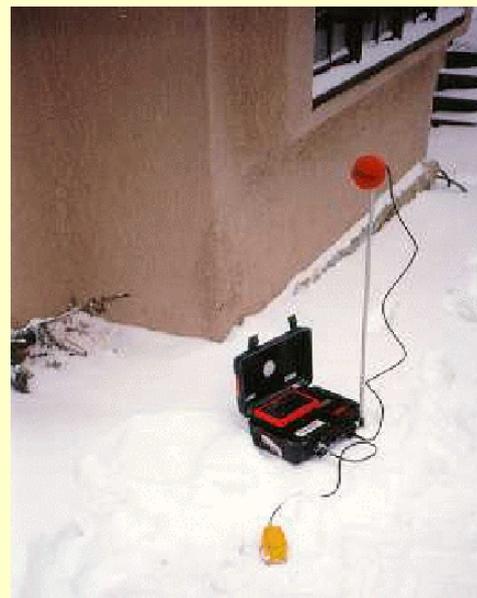
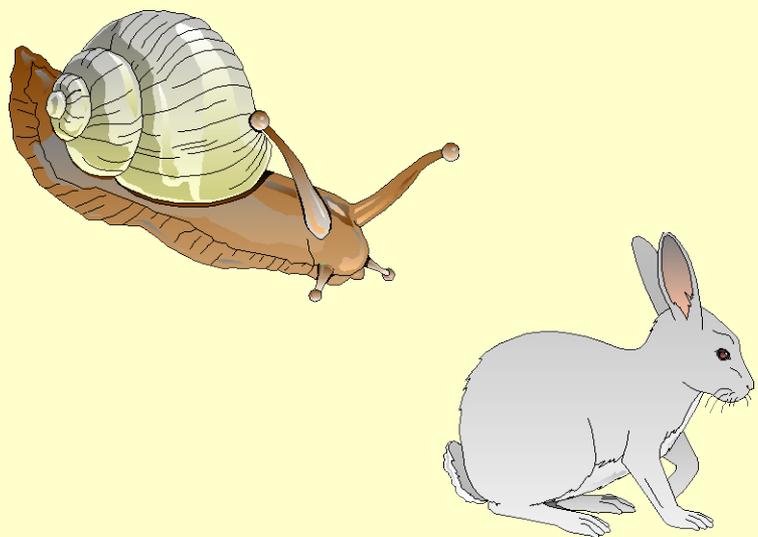
Response Spectra Analysis



General Guidelines

Allow ample time for proper setup of the seismograph. Many errors occur when seismographs are hurriedly set-up. Generally, more than 15 minutes for set-up should be allowed from the time the user arrives at the monitoring location until the blast

Know the temperature. Seismograph have varying manufacturer specified operating temperatures.



Ground Vibration Monitoring

The sensor should be placed on or in the ground on the side of the structure towards the blast. A structure can be a house, pipeline, telephone pole, etc. Measurements on driveways, walkways, and slabs are to be avoided where possible.

Location relative to the structure. Sensor placement should ensure that the data obtained adequately represents the vibration levels received at the structure being protected. The sensor should be placed within 10 feet of the structure or less than 10% of the distance from the blast, whichever is less .



Location relative to the structure. Sensor placement should ensure that the data obtained adequately represents the vibration levels received at the structure being protected. The sensor should be placed within 10 feet of the structure or less than 10% of the distance from the blast, whichever is less .

Ground Vibration Monitoring

Soil density evaluation. The soil density should be greater than or equal to the sensor density. Fill material, sand, unconsolidated soils, flower-bed mulch or other unusual mediums may have an influence on the recording accuracy if not properly dealt with during geophone installation.



The sensor must be nearly level.



Ground Vibration Monitoring

The longitudinal channel should be pointing directly at the blast and the bearing should be recorded



Where access to the structure and/or property is not available, the sensor should be placed closer to the blast in undisturbed soil.



Ground Vibration Monitoring

If the acceleration exceeds 0.2 g, slippage of the sensor may be a problem. Depending on the anticipated acceleration levels spiking, burial, or sandbagging of the geophone to the ground may be appropriate.

The preferred burial method is excavating a hole that is no less than three times the height of the sensor (ANSI S2.47-1990, R1997), spiking the sensor to the bottom of the hole, and firmly compacting soil around and over the sensor.

Attachment to bedrock is achieved by bolting, clamping or glueing the sensor to the rock surface.

Other sensor placement methods.

Shallow burial is anything less than described above.

Spiking entails removing the sod, with minimal disturbance of the soil and firmly pressing the sensor with the attached spike(s) into the ground.



Ground Vibration Monitoring

Sand bagging requires removing the sod with minimal disturbance to the soil and placing the sensor on the bare spot with a sand bag over top. Sand bags should be large and loosely filled with about 10 pounds of sand. When placed over the sensor the sandbag profile should be as low and wide as possible with a maximum amount of firm contact with the ground.

A combination of both spiking and sandbagging gives even greater assurance that good coupling is obtained.



If the acceleration is expected to be:

Less than 0.2 g, no burial or attachment is necessary

Between 0.2 and 1.0 g, burial or attachment is preferred. Spiking may be acceptable.

Greater than 1.0 g, burial or firm attachment is required (USBM RI 8506).

FREQUENCY	PARTICLE VELOCITY	PARTICLE VELOCITY
	0.2g	1.0g
4	3.07	15.40
10	1.23	6.15
15	0.82	4.10
20	0.61	3.05
25	0.49	2.45
50	0.25	1.25
100	0.12	0.60
200	0.06	0.30

Ground Vibration Monitoring

The sensor may be attached to the foundation of the structure if it is located within +/- 1-foot of ground level (USBM RI 8969). This should only be used if burial, spiking or sandbagging is not practical.





Ground Vibration Monitoring

Site conditions dictate certain actions when programming the seismograph.

1. Ground vibration trigger level. The trigger level should be programmed low enough to trigger the unit from blast vibrations and high enough to minimize the occurrence of false events. The level should be slightly above the expected background vibrations for the area. A good starting level is 0.05 in/s.
2. Dynamic range and resolution. If the seismograph is not equipped with an auto-range function, the user should estimate the expected vibration level and set the appropriate range. The resolution of the printed waveform should allow verification of whether or not the event was a blast.
3. Recording duration - Set the record time for 2 seconds longer than the blast duration plus 1 second for each 1100 feet from the blast.

Airblast Monitoring

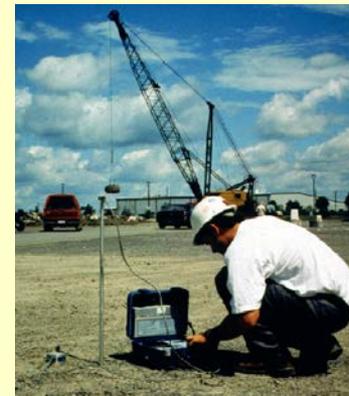
Placement of the microphone relative to the structure is the most important factor.

The microphone should be placed along the side of the structure nearest the blast

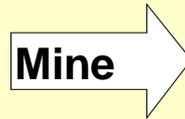
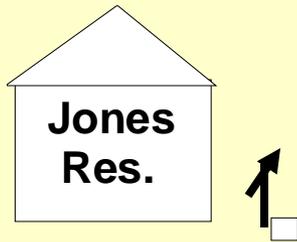
The microphone should be mounted near the geophone with the manufacturer's wind screen attached.



The preferred microphone height is 3 feet above the ground or within 1.2 inches of the ground. Other heights may be acceptable for practical reasons. (ANSI S12.18-1994, ANSI S12.9-1992/Part2) (USBM RI 8508)



Airblast Monitoring



If practical, the microphone should not be shielded from the blast by nearby buildings, vehicles or other large barriers. If such shielding cannot be avoided, the horizontal distance between the microphone and shielding object should be greater than the height of the shielding object above the microphone.



If placed too close to a structure, the airblast may reflect from the house surface and record higher amplitudes. Structure response noise may also be recorded. Reflection can be minimized by placing the microphone near a corner of the structure. (RI 8508)



Airblast Monitoring

Site conditions dictate certain actions when programming the seismograph to record airblast.

1. Trigger level. When only an airblast measurement is desired, the trigger level should be low enough to trigger the unit from the airblast and high enough to minimize the occurrence of false events. The level should be slightly above the expected background noise for the area. A good starting level is 120 dB.
2. Recording duration. When only recording airblast, set the recording time for at least 2 seconds more than the blast duration. When ground vibrations and airblast measurements are desired on the same record, follow the guidelines for ground vibration programming.

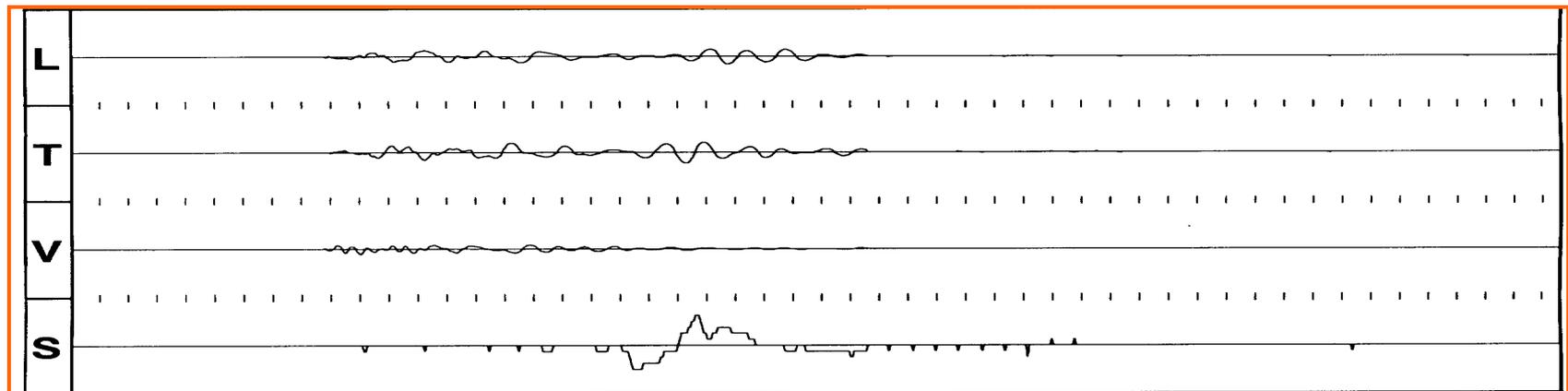
Vibration Reports

Each vibration report will contain a **time history**, **summary**, **general information** and a graphical section.

- The time history shows the particle velocity over time and is the signature for determining blast-induced events.
- The summary section reports the peak particle velocity (PPV) for each trace along with the frequency at the PPV. Displacement and acceleration are calculated from these values. Also reported is the peak airblast pressure in decibels.
- The general information section describes the blasting seismograph location and trigger levels.
- The graphical section lists the scale of the time histories and calibration information.

Regulations that limit ground vibrations specify limits in terms of the **maximum peak** particle velocity in any one of the three perpendicular directions (or components of motion).

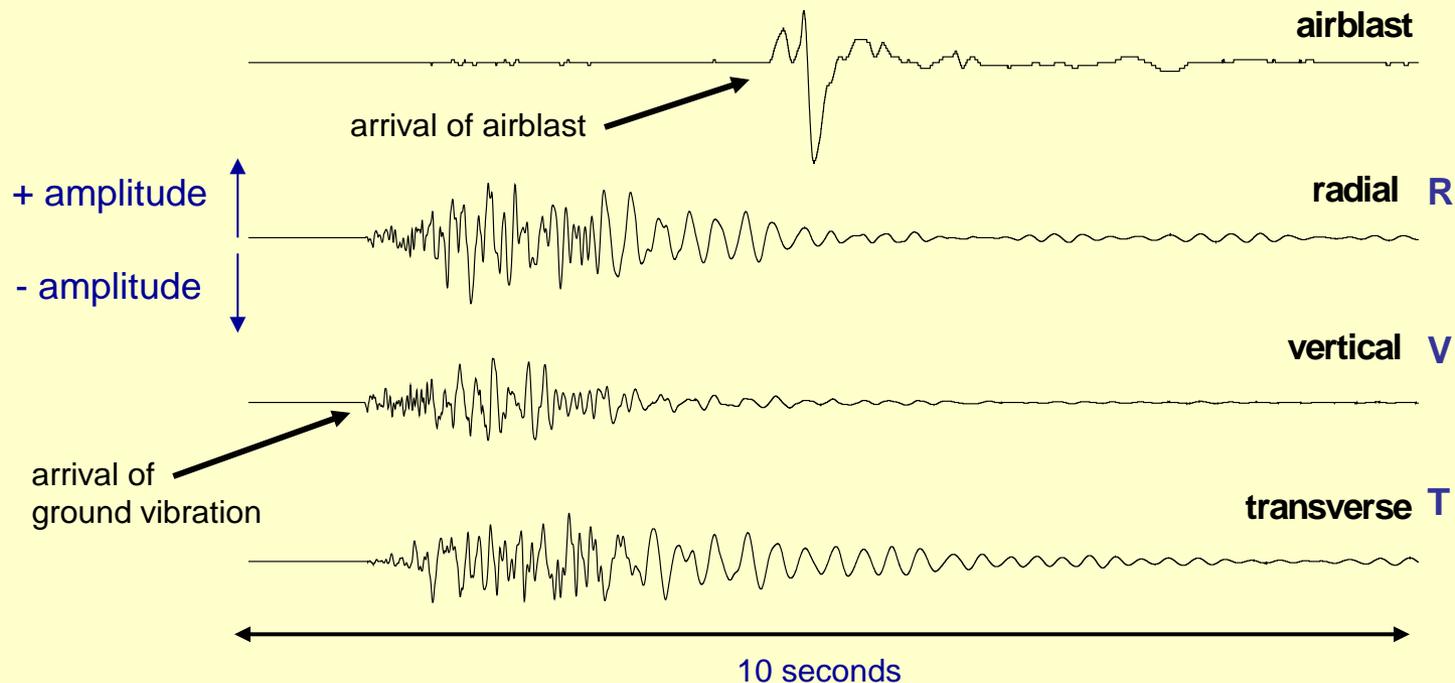
** SAFEGUARD SEISMIC UNIT 2000DK **					
DATE: 09/12/95	TIME: 15:18:06	SN: 2243			
Event: 009	Recording Time: 10				
Client: ROBERTSON					
Operation: BUCKEYE IND. MINING CO.					
SSU Location: ROBERTSON YARD					
Distance to blast: 1385					
Operator: M.MANN/ODNR					
Comments:					
Trigger Level: .05 IN/SEC					
		Summary			
		L	T	V	
		PPV (in/sec)	0.10	0.14	0.07
		PD (in x.001)	2.39	2.97	1.38
		PPA (g)	.02	.02	.02
		FREQ (Hz)	8.0	7.6	16.6
		RESULTANT PPV (in/sec):	0.15		
		PEAK AIR PRESSURE: (dB)	114		
		(psi)	0.00145		
VELOCITY WAVEFORM GRAPH SCALE		SHAKETABLE CALIBRATED: 06/20/95			
TIME = 100 MSEC PER MARK		By GeoSonics, Inc.			
SEISMIC = +/- .64 IN/SEC		Box 779, Warrendale, PA 15095 U.S.A.			
SOUND = +/- 0.00232 PSI		TEL: 412.934.2900 FAX: 412.934.2999			



Blast-Induced Time History Characteristics

The time histories below were recorded over a 10-second interval. Each is a plot of amplitude versus time as the particles oscillate. Several key points regarding the time histories emerge:

- the L, T, and V motions all begin at the same time and have peaks at different times;
- the airblast arrival time is later than the arrival time of the ground vibration, because the speed of sound in air is slower than the speed of sound in rock or soil;
- the V component has an amplitude that is smaller than the R and T components; and
- the number of oscillations per unit time (frequency) are very high in the beginning and decrease and spread out later in the blast time history for the R, V, and T traces.



Vibration Characteristics

The characteristics of time histories that are important to evaluate ground vibration and airblast are:

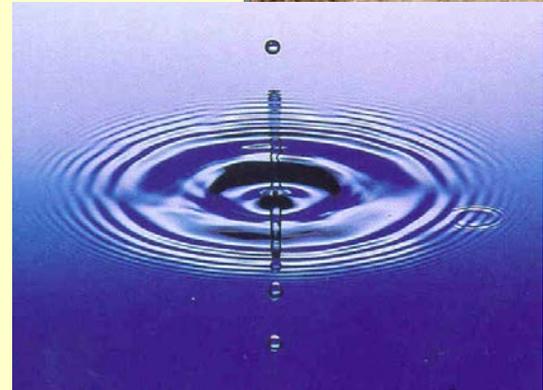
- **amplitude**, or the intensity of particle velocity or airblast,
- **frequency**, and
- **duration** of the time history.

Each characteristic impacts structure response (shaking). Amplitude is the relative strength of the event, frequency is the rate of shaking and duration is the length of the event waveform.

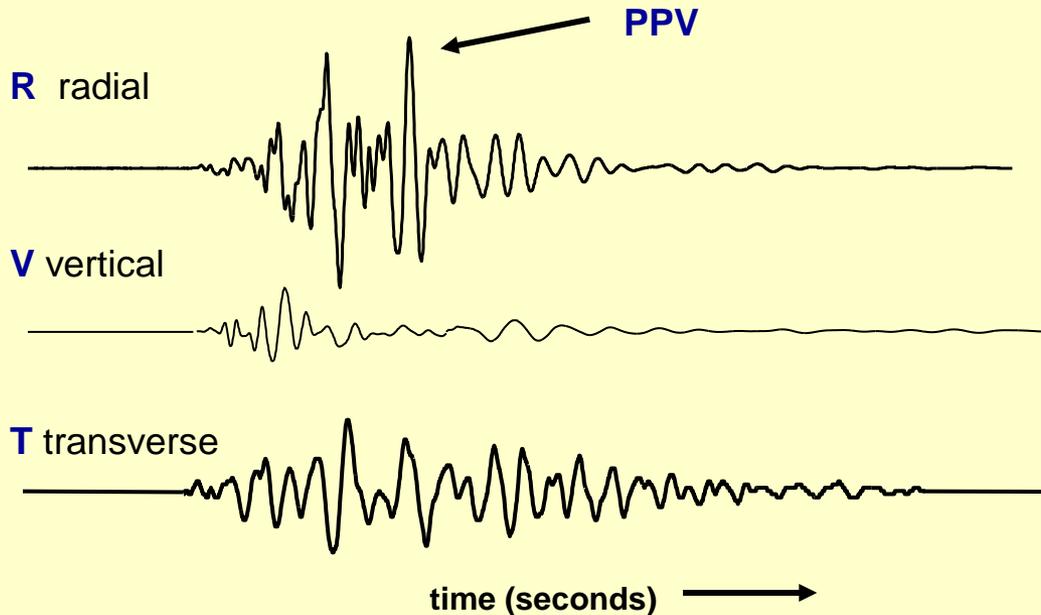
Understanding the impact of vibrations on structures and how they may be modified by blast-design is an important step in limiting offsite impacts.

FACT: A blasting seismograph can measure the effects of blast-design changes on offsite vibrations.

Also, when a blast generates excessive vibrations, the waveform can be used to identify blast design or performance problems.



Amplitude of Ground Vibration: Peak Particle Velocity



The time history is made up of peaks and troughs of motion, the height of any wave is the *amplitude*.

PEAK PARTICLE VELOCITY (PPV) is the largest value of ground-vibration amplitude measured in any one of the component directions.

The **maximum peak particle velocity** is the largest PPV of the three component motions.

In the example shown above, the maximum PPV is a positive peak R component. This amplitude is greater than the other two components of ground vibration (V and T).

Frequency of Ground Vibrations

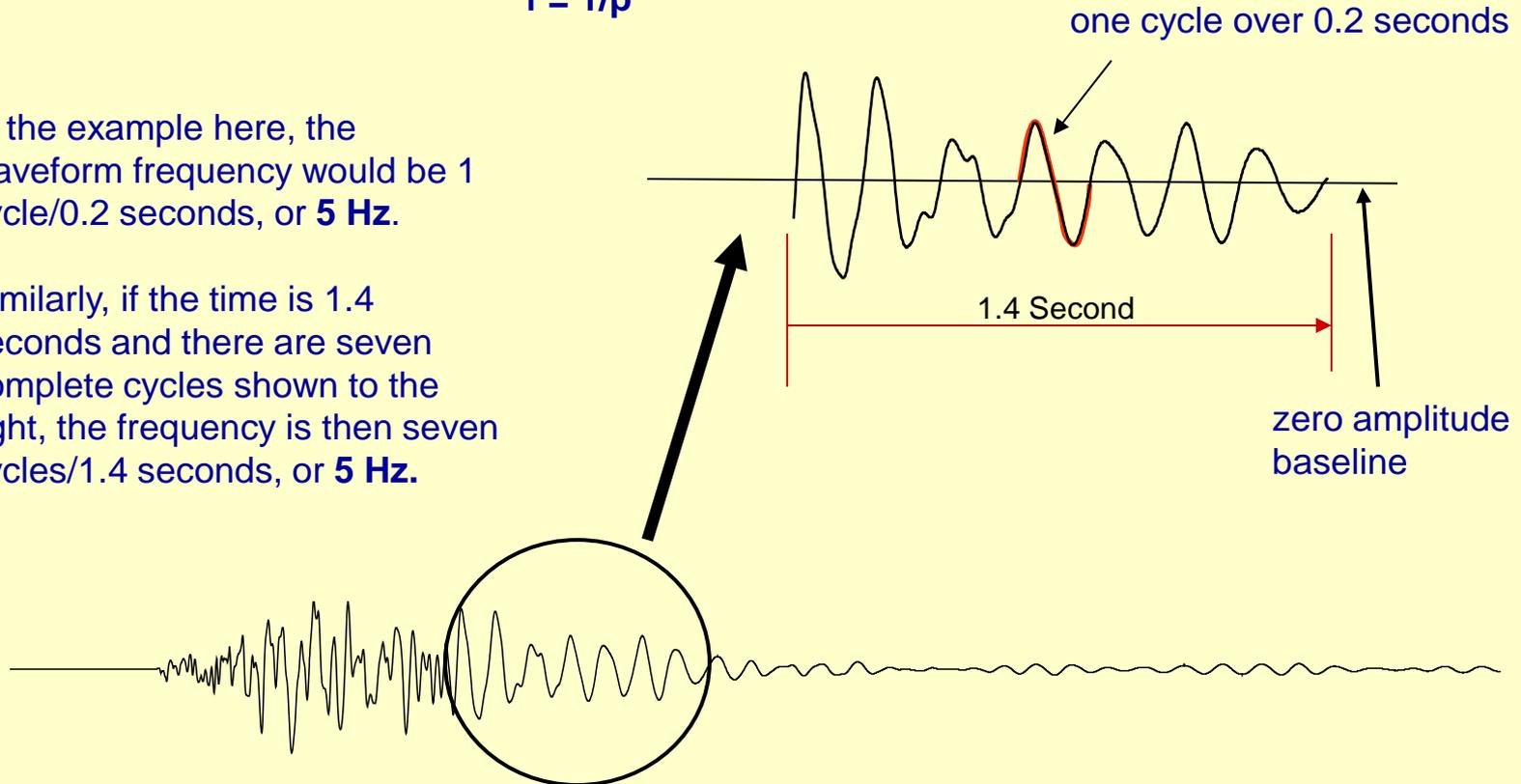
Frequency is the number of cycles or oscillations that a wave completes over 1 second and is measured in cycles per second or Hertz (Hz).

Frequency can also be calculated by the time interval of one complete cycle, a positive phase followed by a negative phase (shown in red). Here the wave meets the zero baseline three times. Frequency is then the number of cycles (in this case, one) divided by the time increment (period).

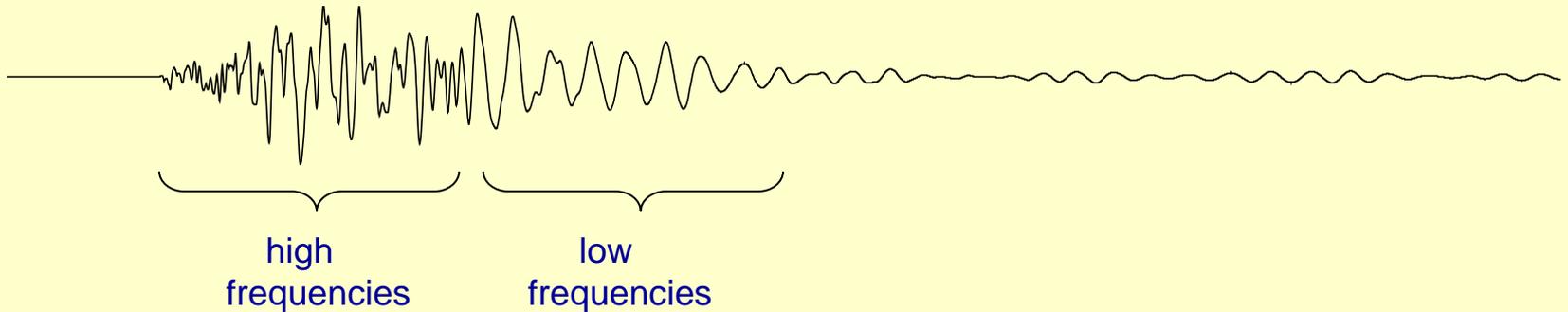
$$f = 1/p$$

In the example here, the waveform frequency would be 1 cycle/0.2 seconds, or **5 Hz**.

Similarly, if the time is 1.4 seconds and there are seven complete cycles shown to the right, the frequency is then seven cycles/1.4 seconds, or **5 Hz**.



Frequency of Ground Vibrations



4-20 Hz are considered low frequencies.

Note that the waveform shown above has both high frequencies, in the beginning where the peaks and troughs are close together in time, and low frequencies, at the end where the waves are farther apart in time.

Low frequencies can develop in certain geological formations (underground voids) and thick soil conditions where high-frequency energy diminishes. Low frequencies also develop with increasing distance from a blast. Some blast timing patterns and blasting methods routinely generate low frequencies.

Low frequency vibrations cause structures to shake the most.

Ground Vibration Characteristics - Displacement

All blasting seismographs measure particle velocities and report the results as time histories. However on occasion it is important to determine the displacement and acceleration of an vibration event.

For simple vibration events, displacement, velocity, acceleration and frequency are all related. If any two components are known, the other two can be calculated.

The displacement of ground vibrations is the distance (D) a particle physically moves in the ground. Distance is reported in inches (in) and can be calculated with the equation:

$$D = V/2 \pi f$$

Where D = Displacement (in)

f = frequency (Hz)

V = velocity (in/s)

$\pi = 3.14$

Displacement equates to the amount a structure is potentially bent or strained and is important for damage assessment.

Ground Vibration Characteristics - Acceleration

The acceleration (A) of ground vibrations is the rate at which the particle changes speed or velocity in the ground. Acceleration is reported in inches per second squared (in/s²) or gravities (g) and can be calculated with the equation:

$$A = 2 \pi f V$$

Where A = Acceleration (in/s²)
f = frequency (Hz)
V = velocity (in/s)
 $\pi = 3.14$

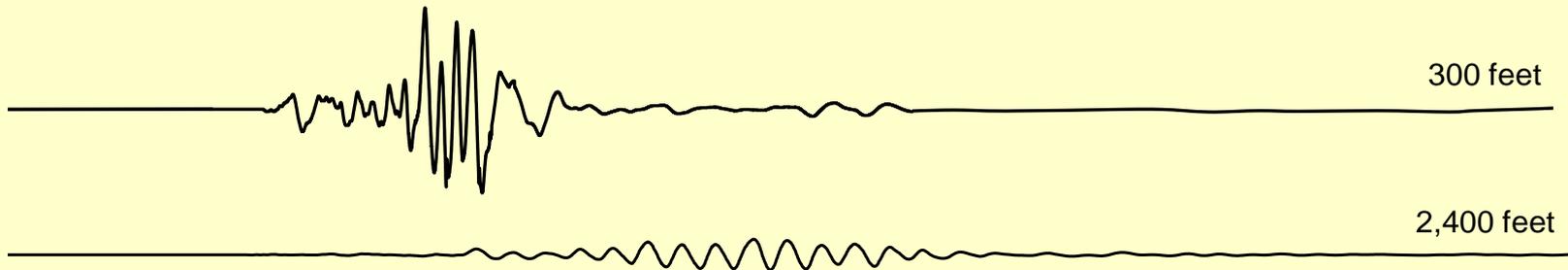
To express acceleration in “g’s” divide the result of the equation above by 386.

Acceleration is important for proper coupling of ground vibration sensors. If the acceleration is expected to exceed 0.2 g, the sensor should be buried or affixed to the ground. If not, the sensor will overcome the force of gravity and provide errant measurements.

Duration of Ground Vibrations

As a ground vibration travels away from a blast site, the duration of the ground vibration tends to *increase* as the wave disperses (or “stretches” in time), whereas the frequency and amplitude tend to decrease. This is shown below for two R components measured near a coal mine casting blast at 300 feet and 2,400 feet, respectively, from a blast.

The longer ground vibration will cause a structure to shake longer. If low frequencies are also present and match the fundamental frequency of the structure, the structure will respond or shake more strongly.



Structure Response

As ground and air vibrations reach a structure, each will cause it to shake. Structure response is dependant on the vibration characteristics (frequency and amplitude) and structure type.

Ground Vibrations enter the house through the basement. This is like shaking the bottom of a flag pole. Movement at the top of the pole depends on how (frequency) and how hard (amplitude) the bottom of the pole is shaken. If shaken at just the right pace, or at the pole's natural frequency, the top will move significantly compared to the bottom. Motion at the top is amplified from the bottom motion.

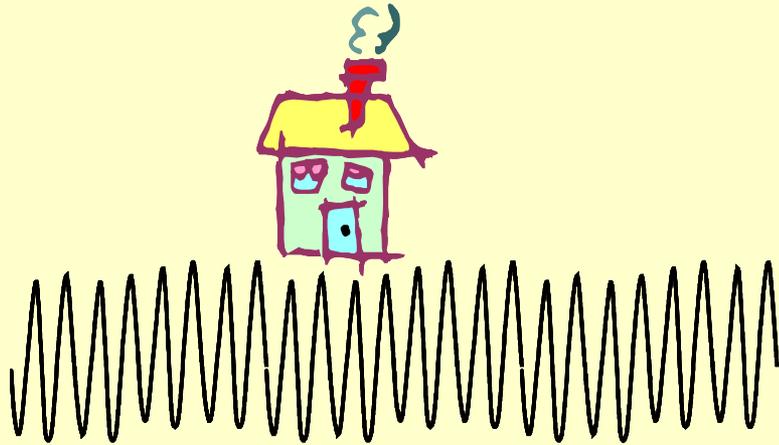
All blast damage studies have measured incoming ground vibrations at the ground surface. The observed structure amplifications were typically between 1 to 4 times the ground vibration. Structure response below ground level is the same or less than the incoming vibrations

Airblast enters the house through the roof and walls. Like ground vibrations, the frequency and amplitude of the vibrations affect structure response. However the low frequency events (concussion) that most strongly affect structures is normally only a one or two cycle event.

Due to the different arrival times of ground and air vibrations, occupants may feel two distinct impacts on the house.

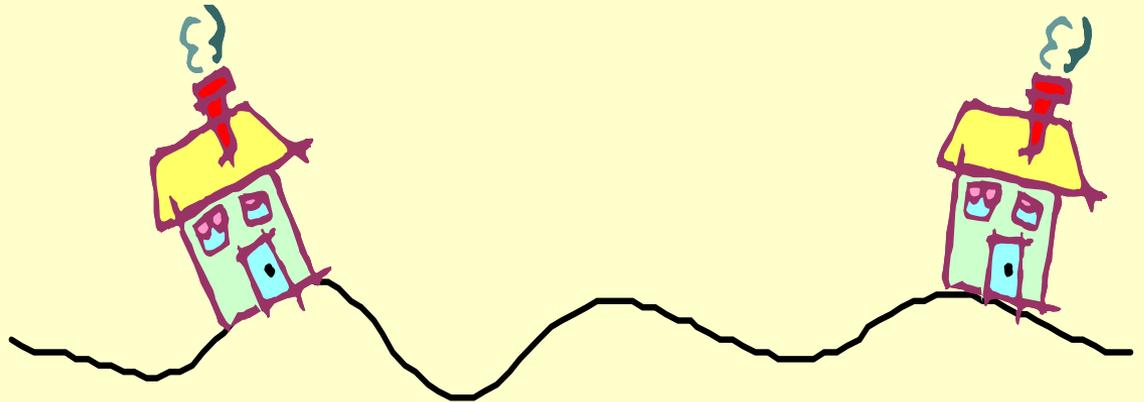


Ground Vibration Structure Response



High frequencies do not promote structure shaking. The length of a single high-frequency wave cycle is short as compared with the dimension of a structure. A structure does not significantly respond to high frequencies.

On the other hand, low-frequency wave cycles are long as compared with the dimensions of structures. Accordingly, low frequencies tend to efficiently couple energy into structures and to promote higher-amplitude, long-duration shaking.



Frequency of Ground Vibrations

Frequency is a very important component of ground vibration, because it affects how structures shake.

When the frequency matches the natural or fundamental frequency of a given structure, the structure will shake more vigorously than the ground vibration or the structure resonates. In other words the incoming ground vibrations are amplified in the upper portion of the structure.

The natural frequency of most residential structures ranges from 4 to 12 Hz.

If the ground frequency is high (above 20 Hz), very little seismic energy transfers into the structure, and the amplitude of structure shaking more closely duplicates ground vibration level.

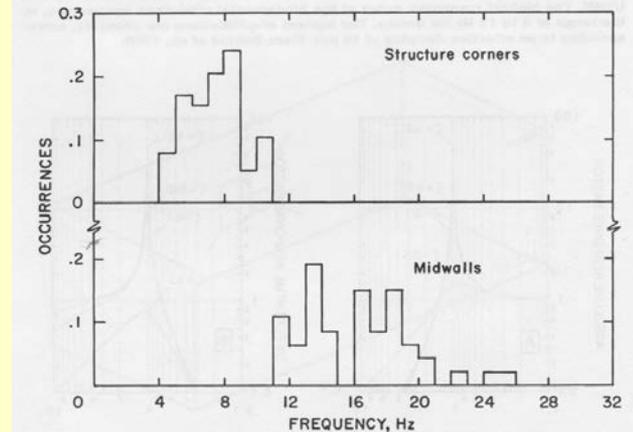
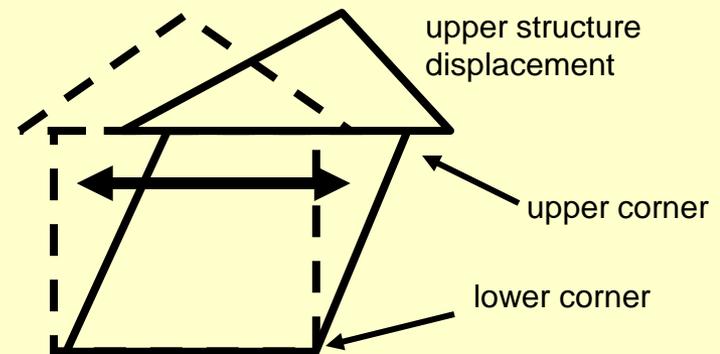


FIGURE 14. Natural frequencies of homes as reported in USBM RI 8507 (Siskind et al., 1980b). Corners represent racking of whole-structure response, and midwalls represent membrane-type flexure with associated secondary noises and rattling. The lighter and more flexible walls have higher natural frequencies and relatively large motions.

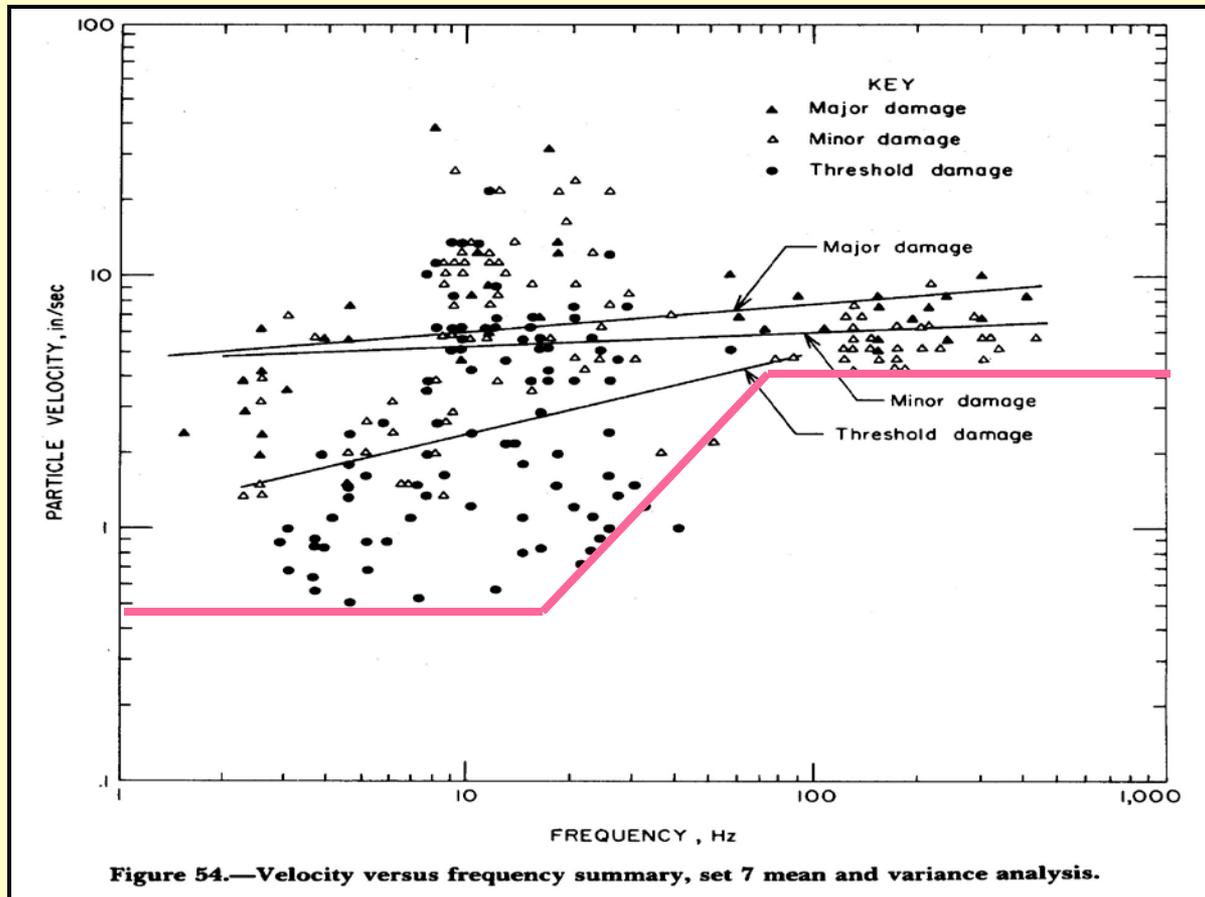
Ground vibrations tend to affect (1) the shaking of a whole structure or (2) differential motions between the upper and lower corners of a structure, resulting in wall strains.



Damage Observations

Damage Classifications

- **Threshold** – Loosening of paint, small plaster cracks at joints between construction elements, lengthening of old cracks
- **Minor** – Loosening and falling of plaster, cracks in masonry around opening near partitions, hairline to 1/8 in. cracks, fall of loose mortar
- **Major** – Cracks of several mm, rupture of opening vaults, structural weakening, fall of masonry, load support ability affected



US Bureau of Mines – Recommended Safe Levels

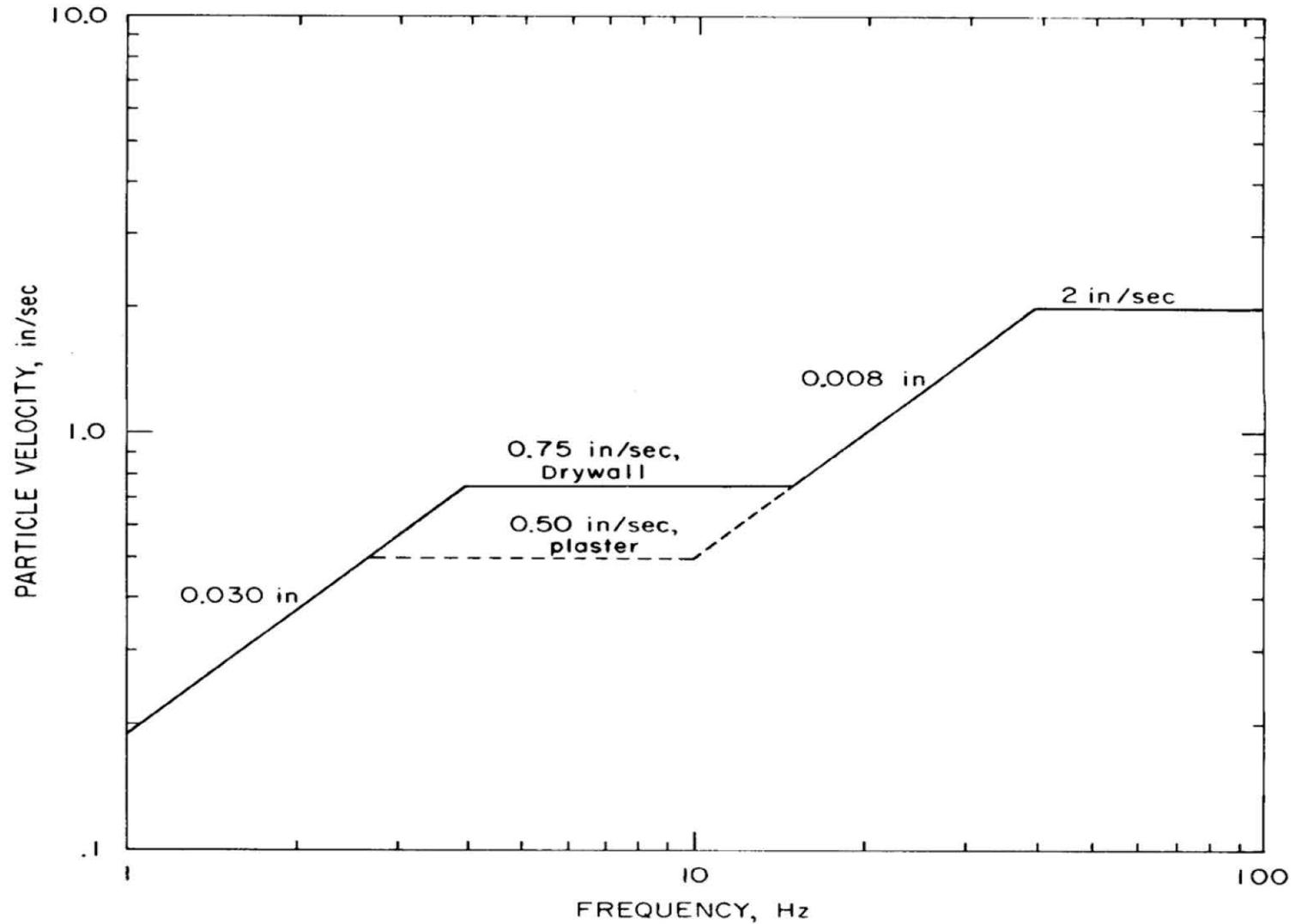
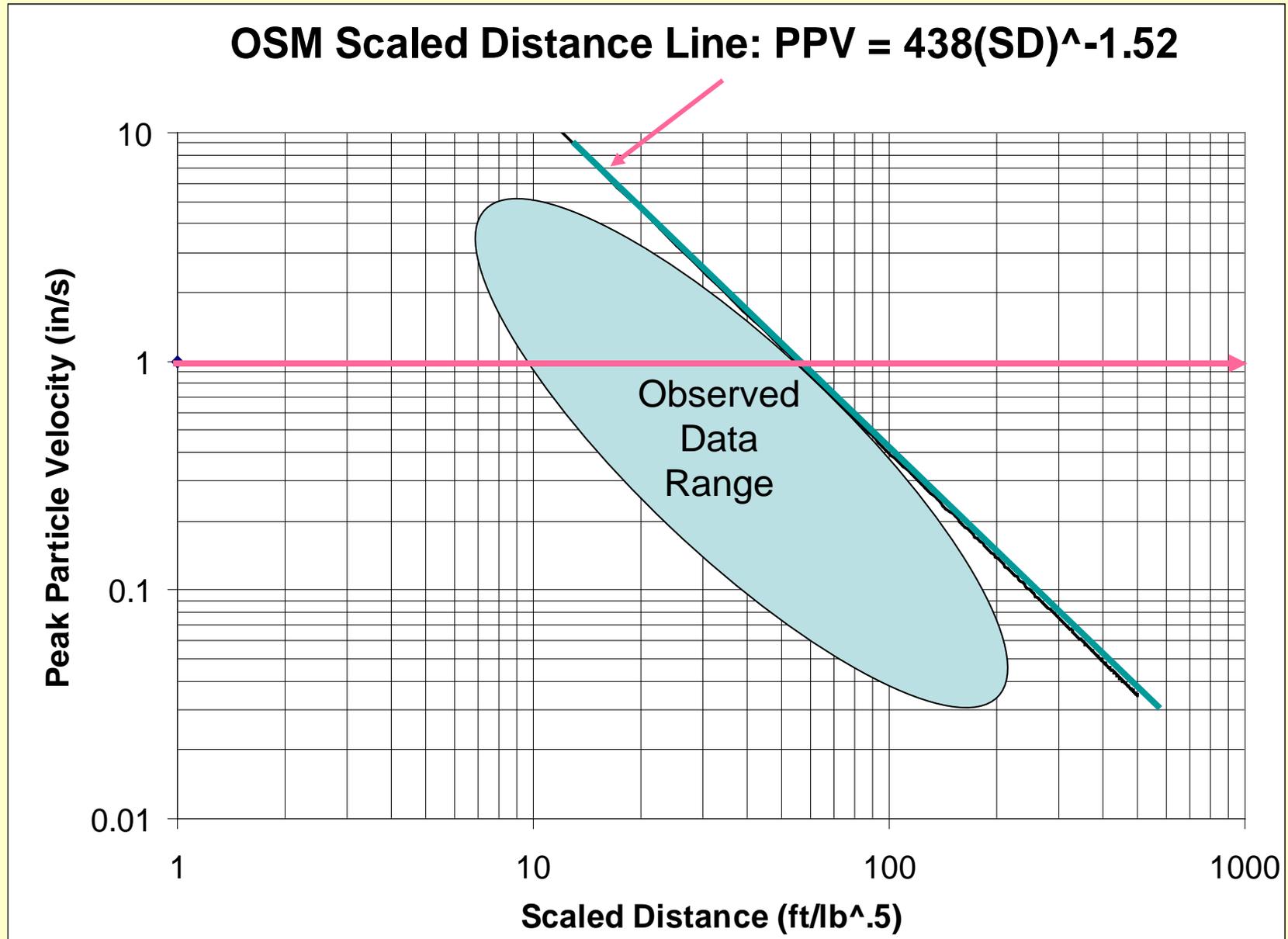


Figure B-1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.

SD/PPV Relationship, Coal Mines

Based on USBM RI 8507 coal mine data set, Table 2, Two standard deviations from the mean.



Causes of Excessive Ground Vibrations

The blaster has some control over the causes of excessive ground vibrations.

Uncontrollable factors:

- Spatial relationships and distance between the blast site and adjacent structures:
 - The closer the distance, the higher the amplitude of ground vibrations
- Geology between the blast site and adjacent structures:
 - Strong, competent rock tends to promote high frequencies and high vibration amplitudes
 - Weak, fractured rock tends to promote low frequencies and low vibration amplitudes
 - Seismic energy traveling in the direction of major rock jointing or faults will tend to promote high vibration amplitudes
- Soils on which a structures sits
 - Low density soils foster low frequency ground vibrations

Controllable factors:

- Maximum charge weight detonated within 8 milliseconds:
 - Seismic energy from individual blast hole charges that detonate within 8 milliseconds tends to be additive, increasing vibrations with increased charge weight
- Charge diameter and charge coupling within boreholes:
 - The larger the blast hole diameter, the greater the ground disturbance at the blast site
 - Well-coupled charges in the blasthole create higher vibrations than do decoupled charges
- Direction of initiation:
 - Certain timing between rows and between holes in a row may reinforce seismic energy
- Confinement:
 - Heavily confined blasts, such as pre-split and sinking designs, promote excessive vibrations

Methods to Reduce Ground Vibrations

1. Reduce the weight of explosive per delay by decreasing the hole size or bench height and decking charges.
2. Reduce burden and spacing to reduce confinement.
3. Eliminate buffer shooting, and make sure that the toe is cleaned of broken rock.
4. Reduce hole depth and subdrilling, if used.
5. Maximize internal relief by using one to two free faces to blast, thereby either increasing or decreasing delay times while maintaining desired muckpile shape and degree of fragmentation.
6. Change or modify the direction of initiation, especially for pre-split lines.
7. Reduce the total time of the blast (a) to minimize the duration of the ground motions (by reducing the number of blastholes) or (b) to reduce the delay times.

Some blasters have found that increasing the charge weight per delay has reduced vibrations. However, this approach—as well as many others—should be guided with technical assistance from the explosives suppliers.

The use of accurate electronic delays should, in theory, control vibrations. As programmable delays become more widely used, the benefits to vibration control should become more widely published.

Air Vibrations or Airblast



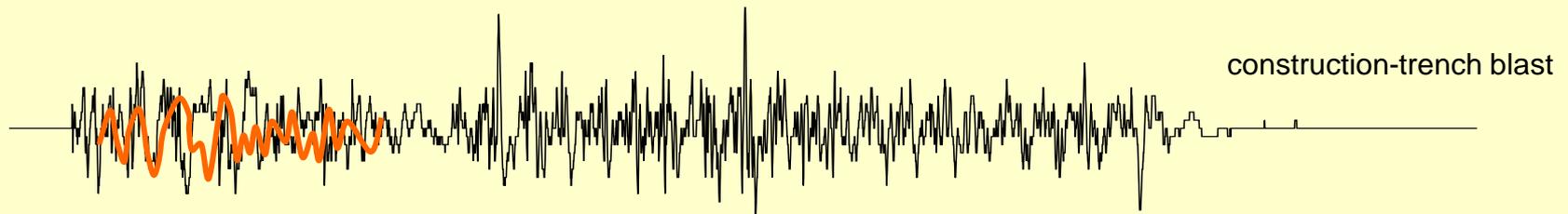
Airblast is a pressure wave time history that creates a push (positive pressure) and pull (negative pressure) effect. For simple time histories, frequency can be determined with the same methodology as used for ground vibrations.

Frequencies associated with airblast will vary depending on the type of blasting. The coal-mine pressure pulse shown above has a low frequency of about 2-Hz

The trench-blast airblast time history for the blast shown below is predominately high frequency. This blast would be audible but the coal mine blast would be in-audible (<20 Hz, concussion wave).

However, if the trench-blast airblast time history is carefully inspected, one can detect the high-frequency components (41 Hz) “riding” on top of an underlying lower frequency (4 Hz) wave (highlighted in orange below).

Like ground vibrations, the low-frequency components will cause structures to more strongly shake.



Airblast Sources

Air Pressure Pulse – rock displacement at the face, low frequency

Rock Pressure Pulse – Seismically induced from the ground at the blasting seismograph

Gas Release Pulse – Gases venting through the fractured rock, low frequency

Stemming Release Pulse - Blow-out of the stemming, high frequency on top of the air pressure pulse

Noise – High frequency from Det cord or surface delays

Click to see
Stemming
Release
Pulse



28N1-HW
12th March 2002

Click to see
Air
Pressure
Pulse



Click to
see
Gas
Release
Pulse

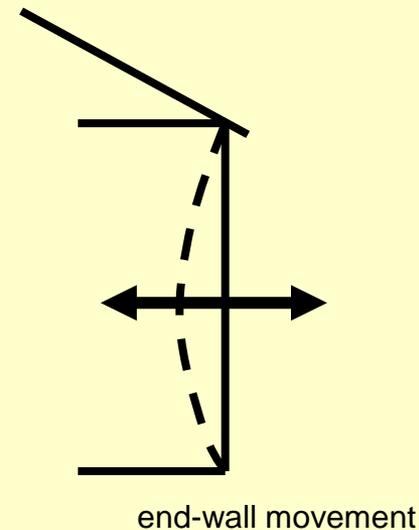
Airblast Structure Response

Air blast can cause both whole structure and mid-wall response. If a high amplitude pressure wave has mostly low frequency energy (< 12 Hz), the whole structure will respond similar to ground vibrations. If a high pressure wave has mostly mid-range frequencies (12-20 Hz) the wave will cause the mid-walls to bend in response, like the head of a drum when it is struck. The larger the wall-surface area, the greater the wall response to the airblast. Two-story structures are more sensitive to airblast than are one-story structures.

When mid-walls shake, loose objects on the wall or sitting on shelves rattle and generate noise within structures. This noise is often startling to the residents and creates concern that the structure is being damaged by the blasting. This, in turn, promotes fear and sometimes anger, especially if:

- The air-pressure pulse is high in amplitude and long in duration and/or
- There is a long time interval between the ground vibrations and the airblast arrival.

Structural damage associated with airblast (other than glass breakage) has ever been documented from airblast within recommended safe levels (133 dB).



Airblast Scaling

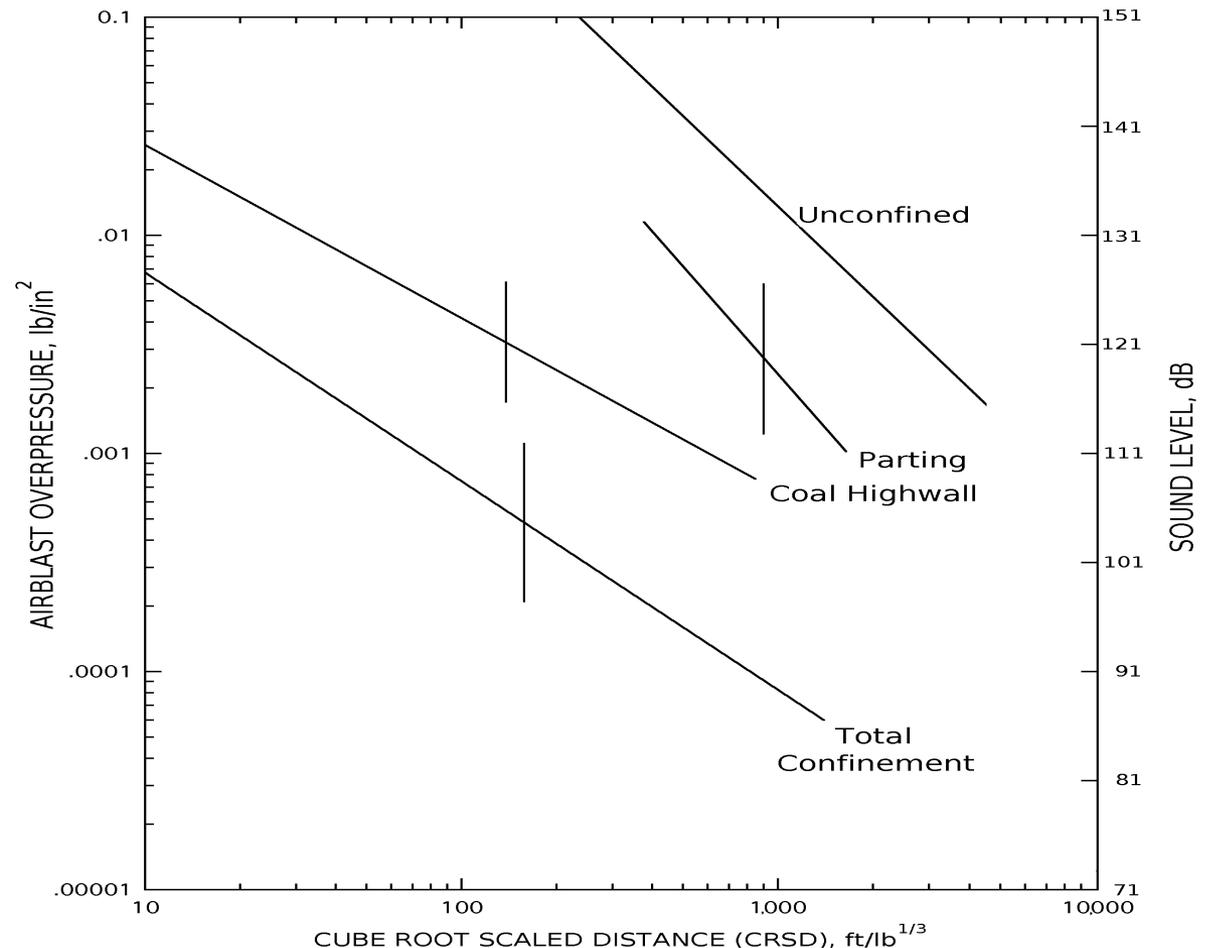
- Ground vibration (square root SD) typically attenuates over distance at a higher rate than Airblast (cube root SD)

- Using cube root scaled distance results in a flatter line, less drop-off of energy over distance

- Perceptible airblast levels may occur at much greater from blasting distances than perceptible ground vibration

- Cube root scaling of the charge weight ($CW^{1/3}$) is similar to square root scaling ($CW^{1/2}$)

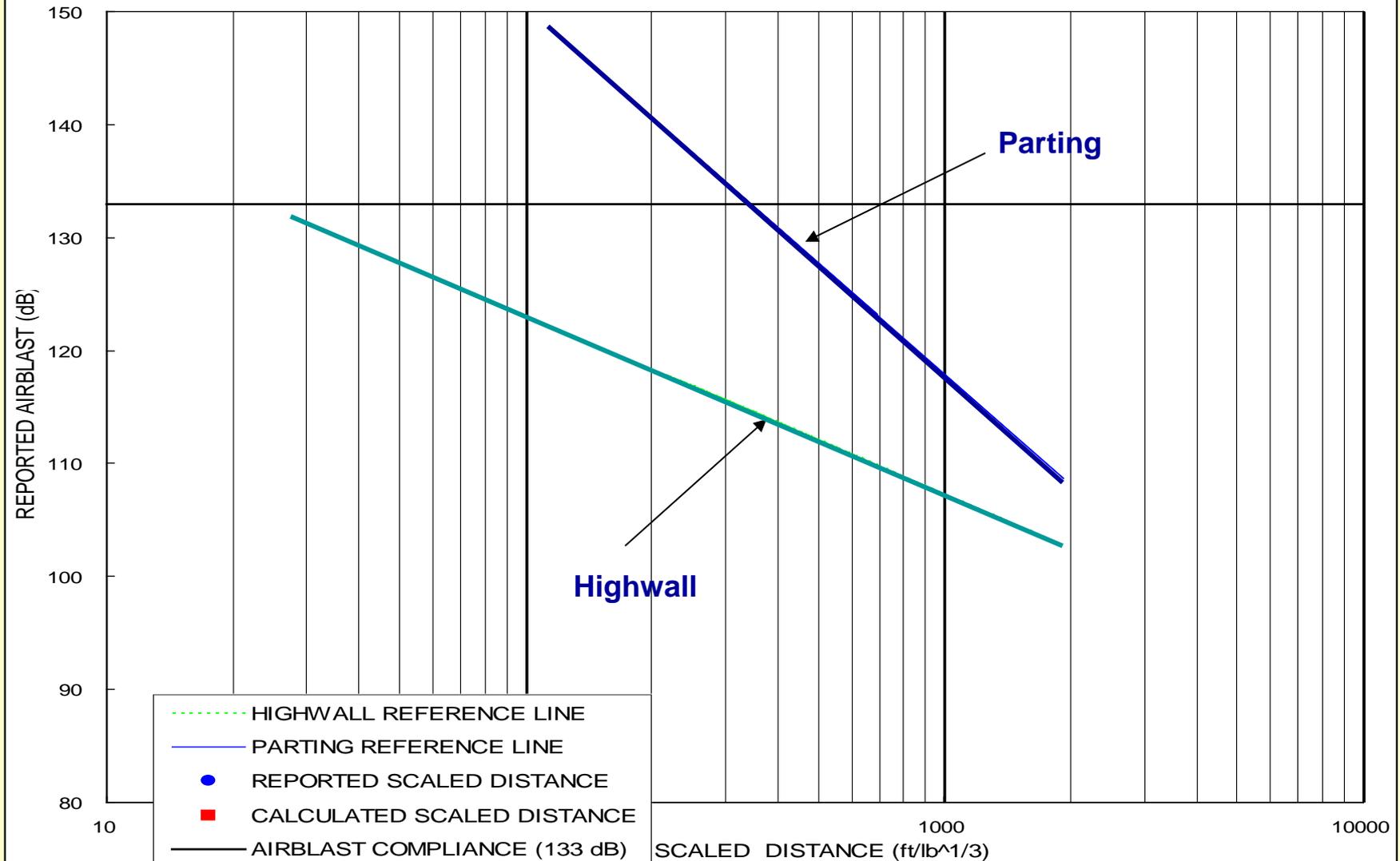
- Airblast strongly impacted by confinement**



Airblast Predictions – SD/dB

Based on USBM 8584 coal mine data, Typical highwall and parting blasts, Expected relationships

AIRBLAST ANALYSIS



Causes of Excessive Airblast

Excessive airblast can be caused by:

- Insufficient length and/or quality of stemming material, both of which promote blow-outs:
 - Improper size and angularity of stem material will promote low-friction sidewall forces that cannot withstand detonation pressures
 - Stem lengths that are too short will most likely be ejected
 - Gas escaping along the highwall face:
 - From insufficient front-row burden
 - Through rock fractures
- 
- Detonating cord trunk lines being detonated on the surface
 - Delay sequencing across the front face relative to hole spacing
 - Adverse atmospheric conditions that tend to convey or focus airblast:
 - Wind velocity and direction
 - Temperature inversions in the early to mid-morning,
 - Windless days when warm temperature air exits over colder temperature air on the ground surface and this interface is relatively low in elevation
 - Lightly confined blasts, such as parting or secondary blasting
 - Airblast may be enhanced from ridge to ridge, up to 300% over flat terrain
 - Topographic features may enhance airblast down valleys

Methods to Reduce Airblast

1. Use sufficient stem length (at least 0.7 times the burden).
2. Use an angular, crushed-rock product of the correct size distribution appropriate for the hole diameter.
3. Check the free faces for excessive fracturing from back break and the presence of mud seams or voids; load the front row of holes accordingly.
4. Conduct blasting in the afternoon when temperature inversions are least likely to persist. Contact a local airport to find out the elevation of the cloud ceiling.
5. Blast when wind conditions are favorable (e.g., either in directions away from structures or at low velocities).
6. Use non-electric, shock-tube initiation systems instead of detonating cord.

Human Response to Vibrations

Ground and air vibrations affect structure shaking in different ways. However, to the residents inside structures, these differences cannot be detected. Human response to blasting is subjective. No two persons will react in the same manner to any one vibration event.

Unfavorable reactions to vibrations that result in complaints being voiced are usually based on annoyance, fear of damage, and the fact that a structure shaking is startling to its residents. It is extremely rare that safe blasting practices damage structures.

Airblast damage is chiefly limited to the cracking of glass window panes. A reasonable safe limit for this type of damage is 140 dB (although this is far above the level that humans will tolerate).

Hairline wall cracks in interior drywall and plaster represent threshold damage from ground vibrations. Keeping ground vibrations at structures below 0.50 ips will prevent these defects from occurring.

Past experience in human response to blasting has revealed that persons inside structures can detect, and will object to, air and ground vibration levels far below those that could damage structures.

FACTS:

- Low amplitude airblast (110 to 117 dB) can cause glass window panes and mid-walls to rattle, generating noise inside structures.
- Above 117 dB to 120 dB, airblast may cause some annoyance and fright.
- Ground vibrations as low as 0.02 ips are perceptible to residents inside structures.
- Low frequency ground vibration events are most annoying to people

Flyrock

Material that is ejected from a blast site that travels through the air or along the ground. Flyrock may be rock or soil. Any size material is capable of damaging property or injuring people.

The Single Factor Of Surface Mining That Is Most Likely To Cause A Fatality!!!

Flyrock control is essential. The blaster is responsible for securing the area around the blast site where flying debris may occur.



Flyrock

Fly rock can be cast thousands of feet from a blast. The most dangerous source is ejection from a crack or weak zone in the highwall face where gases violently vent. This action is akin to a rifle where the expanding gases eject a projectile. Frequently the ejection of stemming out of the top of a blast hole is called **rifling**.



[Click to observe rifling and face venting](#)

A blast that is designed to horizontally displace the overburden material with the explosive energy is called **cast blasting** or and may be referred to as “Engineered” fly rock. This material move in a controlled safe manor. The blast appears well controlled and non-threatening.



[Click to observe cast blast](#)

Flyrock Damage



Flyrock damage is quite obvious when a structure is hit. Holes and marks are very visible.

A rock that lands harmlessly in a field may not appear to be a large issue. However, mowing and tilling become hazardous when rock is struck by farm equipment. Rock through timber stands mar trees and potentially impact the market value.

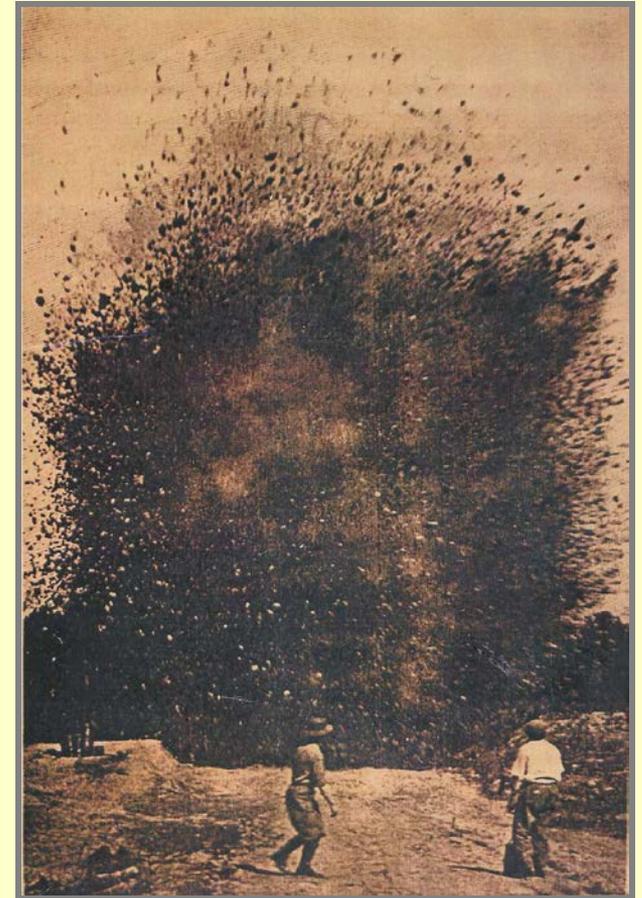
In areas of steep slopes, a rock set in motion by the explosive energy may roll hundreds of feet. In this instance the rock rolled through a trailer down slope from the mine. Children were playing in the front yard at the time. Fortunately no one was injured.



Causes of Flyrock

Often, the factors that cause excessive airblast and ground vibrations have the potential to cause flyrock as well. Flyrock is the number two killer in mining operations. For this reason, it is crucial that blasters understand and control the factors that can create flyrock. Some of the common causes of flyrock are:

1. Overloaded blastholes with excessive amounts of explosives
2. Heavily confined charges or the lack of relief (eg. lift blasts)
3. Explosives loaded into incompetent materials (eg. mud seams, fractures, and/or voids)
4. Insufficient front-row burden, causing front-face blowouts
5. Burdens and spacings too close together (resulting in high powder factors)
6. Inadequate/insufficient stemming material
7. Inadequate delay between holes in the same row or between rows; detonators firing out of sequence
8. Deviation of blast hole detonation from the intended sequence
9. Changing geology or rock type
10. Spacing and burden exceeds borehole depth
11. Angled boreholes
12. Secondary blasting
13. Human error, improperly loaded blasts



Controlling Flyrock

1. Accurately measure the burden for each blast hole, and be aware of the true burden for each hole along the free faces.
2. Be aware of the powder factor and total charge-weight loaded, so that holes are not overloaded; always measure explosive quantities or tape the holes while loading.
3. Insist on effective communication between the driller and the blasting crew, so that the driller conveys information regarding unusual conditions (for example, mud seams, voids, or other weak layers) during drilling.
4. Use adequate stemming and stem through incompetent zones. Use crushed stone for stemming.
5. Place primer lower in the hole, increase delays between rows, reduce burden in back rows



Public Relations

In responding to blasting complaints, whether they are claims of annoyance or structure damage, it is always the best practice to:

- Respond immediately and do not delay direct contact with the complainant;
- Make personal contact;
- Be knowledgeable of the blast creating concern and be prepared to explain any unusual circumstances that may have contributed to higher than usual offsite noise or vibrations;
- Provide assurance that blasting is not causing any damages; and
- Be willing to respond to any future concern.

Make a good public-relations program part of your everyday blasting practices.

Part I: Review Questions and Discussion

Answer as many of the following questions as you can before moving to the next slide, where you will find the answers.

1. List the three directions of ground vibration that blasting seismographs measure.
2. Select the three most important characteristics of blast vibrations that can often be controlled by the blaster:
 - a. Ground vibration amplitude, wave speed, and frequency
 - b. Ground vibration amplitude, frequency, and time duration
 - c. structure response, frequency, and wave length
3. True or false: The temperature at the ground surface is more important than wind speed and direction with respect to controlling airblast.
4. What is the name of the machine or device used to measure ground vibrations and airblast?
5. What is the unit of measurement for air vibrations from blasting?
6. What is the unit of measurement for ground vibrations from blasting?
7. List three things that can be done to control airblast.

Part I: Answers

1. Radial (R), vertical (V), and transverse (T). The R direction of ground vibration is sometimes referred to as longitudinal (L).
2. b. is correct.
3. False; wind speed and direction can cause focusing downwind. Air temperature at ground level is not as important as a temperature inversion, in which colder air exists on the ground is covered by warmer air, above in the atmosphere.
4. A blasting seismograph.
5. Decibels (dB).
6. Inches per second (ips).
7. Use adequate (with respect to both length and type) stemming material.
Eliminate the use of detonating cord.
Do not blast during adverse weather conditions.

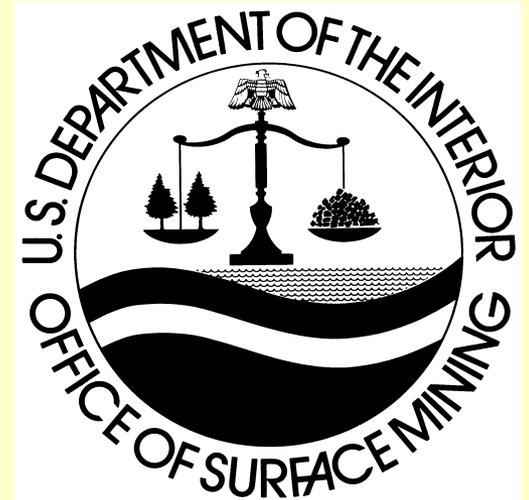
Part II: Office of Surface Mining Reclamation and Enforcement

The Office of Surface Mining Reclamation and Enforcement (OSM) was created when Congress passed the Surface Mining Control and Reclamation Act of 1977 (SMCRA). OSM is responsible for the protection of citizens and the environment during surface coal-mining and reclamation operations. The law creates performance standards, one of which deals with the use of explosives.

SMCRA AND EXPLOSIVES USE

SMCRA was written to ensure that explosives are used only in accordance with existing State and Federal law, as well as the regulations promulgated by State and Federal regulatory authorities. The five SMCRA performance standards governing the use of explosives require:

1. Issuing written notification of blasting schedules and warning signals;
2. Maintaining written records of each blast for a period of at least 3 years;
3. Limiting the use of explosives so as to prevent (a) injury to persons, (b) damage to offsite property, (c) impacts underground mines, and (d) modifications to ground or surface water outside the permit area being blasted;
4. Training and certifying blasters; and
5. Conducting, upon the request of a resident or owner of a man-made dwelling or structure within ½-mile of any portion of the permitted area, a pre-blasting survey of such structures and submitting the survey to the regulatory authority, as well as a copy to the resident or owner making the request.



OSM Regulations

STATE-SPECIFIC REGULATIONS

OSM assists States in developing State programs to regulate surface coal-mining and reclamation operations within their jurisdictions. These programs must implement requirements that are at least as stringent as those mandated by SMCRA. At the same time, State regulations may reflect local requirements and local environmental and agricultural conditions. For more information on State programs, go to

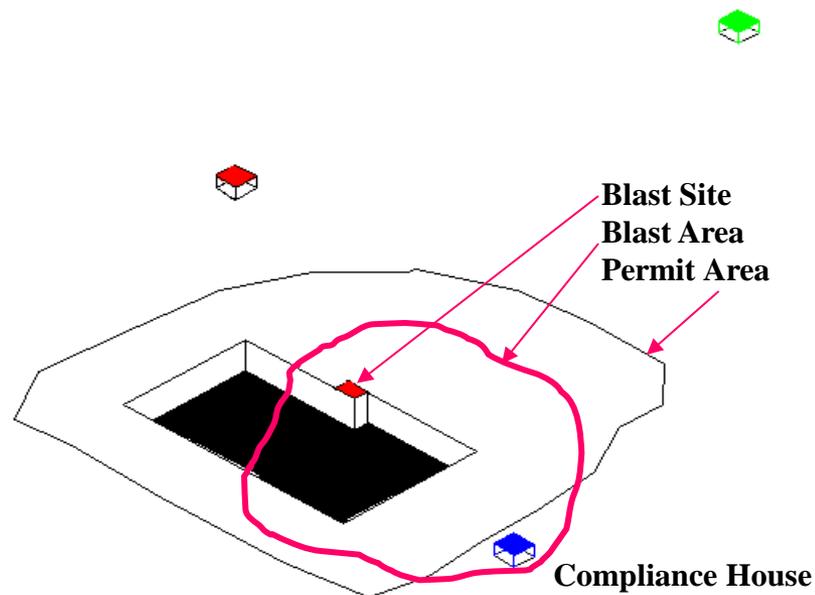
<http://www.osmre.gov/stateregindex.htm>.

DEFINITIONS

Permit area is the area in which the mining company may disturb the surface during mining and reclamation operations.

Blasting area is the area in which concussion (airblast), flying debris (flyrock), or gases from an explosion may cause injury to persons.

Blasting site is the perimeter of the loaded blast holes.



Blasting Plan

Blasting Plan - 30 CFR 780.13

- A plan must be prepared as part of the permit application, on how the blasting operations will comply with the regulations; The plan is subject to public comment.
 - Propose the limits for ground vibrations and airblast
 - Provide the basis for the limits
 - Describe the methods to be used to control the adverse effects of blasting
- The plan must include a description of any system to monitor the adverse effects of blasting (ground vibrations, airblast and flyrock) and include:
 - The type, capability and sensitivity of the blast monitoring equipment
 - Blasting Seismographs
 - Video equipment
 - Any proposed procedures, and
 - Locations of any monitoring.
- If blasting is proposed within 500 feet of an active underground mine, prior to permit issuance, MSHA must grant approval of the plan.

Certified Blasters

Certified Blasters – 30 CFR 850

- **All blasting operations at coal mines must be under the direct supervision of a certified blaster.**
- Blaster means a person directly responsible for the use of explosives in surface coal mining operations who is certified
- To become certified, blasters must:
 - Receive training on the technical aspects of blasting
 - Receive training on Federal and State rules
 - Complete an application
 - Pass a written examination on the training requirements
 - Possess practical field experience
 - Practical knowledge
 - Understands the hazards
 - Exhibits conduct consistent with the responsibility
- Blaster Certification
 - Fixed period of time
 - May be suspended or revoked
 - Re certification is required
- Upon request, the certification must be presented
- Blasters may not delegate their responsibility to non-certified blasters.



Performance Standards

The performance standards must be followed unless the permit specifies otherwise. There are two sections:

- Surface coal mines area at 30 CFR 816.61-68
- Underground coal mines are at 30 CFR 817.61-68

Each performance standard is virtually identical. For brevity only the surface mining standards will be discussed. If you have an underground mine, be sure to check the underground performance standards.

Performance Standards - General

General Requirements – 30 CFR 816.61

- Comply with all State and Federal blasting rules
- Certified blasters must carry certificates or have them at the mine
- The certified blaster and one other person shall be present at the firing of a blast
- The certified blaster will know the blast plan and site specific performance standards
- The certified blaster will give on-the-job training to people on the blasting crew

- Anticipated Blast Design
 - Is required if blasting is proposed within 1,000 feet of any dwelling or within 500 feet of an underground mine;
 - May be submitted as part of the mine plan or at any time thereafter but before blasting within the distances above,
 - Should include sketches and a description of the anticipated blast design including:
 - Drill patterns,
 - Explosives loading and critical dimensions
 - Delay periods
 - Distances to and descriptions of offsite structures;
 - **Discuss how design factors will be used to protect the public from *flyrock, airblast, and ground vibrations*;**
 - Must be prepared and signed by a certified blaster.
 - **Gives RA notice of when blasting is approaching sensitive areas**

Performance Standards - Preblasting Surveys

Preblasting Surveys - 30 CFR 816.62

A preblast survey is a report that documents the existing defects in offsite structures that are:

- (1) not owned by the mine proposing the blasting and
- (2) within ½-mile of the permit boundary.

An “existing defect” includes everything from small hairline cracking to major structural damage; an “offsite structure” is defined as including everything from buildings, dwellings, and structures to pipelines, water-supply systems, and transmission lines.

Preblast surveys conducted before blasting starts are important to protect both:

- the owners of nearby structures (should damages occur, a document exists to show the preblast condition) and
- the blaster or operator (to show that alleged blast damages were in existence before blasting started).

In the preblast survey, the operator shall determine the condition of the dwelling or structure and document any pre-blasting damage and other physical factors that could reasonably be affected by the blasting.

Structures such as pipelines, cables, transmission lines, and cisterns, wells, and other water systems warrant special attention; however, the assessment of these structures may be limited to surface conditions and other readily available data.

Performance Standards - Preblasting Surveys

The mine operator shall:

- Notify, in writing, all residents or owners of dwellings or other structures located within ½-mile of the permit area how to request a pre-blasting survey at least 30 days before blasting.
- Conduct a preblast survey promptly when requested
- Update the survey at the request of the owner if any additions, modifications, or renovations occur to the structure.
- Complete any survey requested more than 10 days before the planned initiation of blasting.
- Provide a written report of the survey signed by the person who conducted the survey.
- Send copies of the report to the regulatory authority and the person requesting the survey.

If the person requesting the survey disagrees with the contents and/or recommendations of the report, they may submit a detailed description of the specific areas of disagreement to both the operator and the regulatory authority.

NOTE: State-specific regulations may require different time periods of notifications and completion of surveys.

Carbondale Coal Company,
Box 1292
Carbondale, PA 19340

April 21, 2000

SUBJECT: Preblast Survey Offer
Powderly Mine, Permit Number TN-2498

Dear Homeowner

Carbondale Coal Company plans to start blasting at the Powderly Mine on or about May 10, 2000. Blasting is required to remove the rock covering the coal. Vibrations, from the blasts, will be noticeable in your home on several occasions; however, no damage is anticipated to your home.

Blasting will be performed in accordance with the standards of the Pennsylvania Coal Surface Mining Regulations. As required by the regulations we are offering a no-cost preblast survey of structures to all homeowners within ½-mile of the permit boundary.

Your property is located within the ½-mile distance and is eligible for the survey. The purpose of the survey is to:

- establish a pre-blasting record as to the existing condition of structures on your property,
- identify any structures or contents that may be sensitive to vibrations, and
- initiate communications between the mine manager and adjacent homeowners about the blasting.

Douglas Consulting will conduct the preblast surveys. The survey will consist of pictorial, narrative, and graphic sections which describe the current condition of the structures on your property. You will receive a copy of the survey when it is completed.

If you contact us by May 3, 2000, we will conduct the survey prior to initiation of any blasting. If you contact us after that date, we will do the survey but it may not be done prior to blasting.

To accept this offer and arrange for a free preblast survey, submit your request in writing, including your name, address, home and work telephone numbers, to our office or the State office. When complete, a copy of the survey report will be provided to you and the State office.

The State's office address is: Pennsylvania DEQ, Box 6899, Pottsville, PA 19455.

After you review the report, you may submit any disagreement in writing to our office and the State office. In the future, you may also request a follow-up survey if additions or renovations are made to your home.

If you have questions regarding this letter or blast vibrations, please call me at 830-1414 or the State office at 245-5893.

Sincerely,

John Smith, Superintendent

Performance Standards - Blasting Schedule

Blasting Schedule – 30 CFR 816.64

A blasting schedule outlines when blasting operations will occur during the day barring any unforeseen circumstances. The schedule must describe the hours in which blasting will be conducted between sunrise and sunset.

The mine operator shall:

- publish the schedule in a newspaper near the mine at least 10 days, but not more than 30 days, before blasting starts.
- give copies of the schedule to local governments and public utilities and to each residence within 1/2 mile of any proposed blasting site.
- republish and redistribute the schedule at least every 12 months
- revise and republish the schedule whenever the area covered by the schedule changes or actual time periods for blasting significantly differ from the prior announcement.

Performance Standards - Blasting Schedule

The blasting schedule shall contain, at a minimum:

- Name, address, and telephone number of the operator,
- Identification of the specific areas in which blasting will take place,
- Dates and time periods when explosives are to be detonated,
- Methods to be used to control access to the blasting area, and
- Type and patterns of audible warning and all-clear signals to be used before and after blasting.

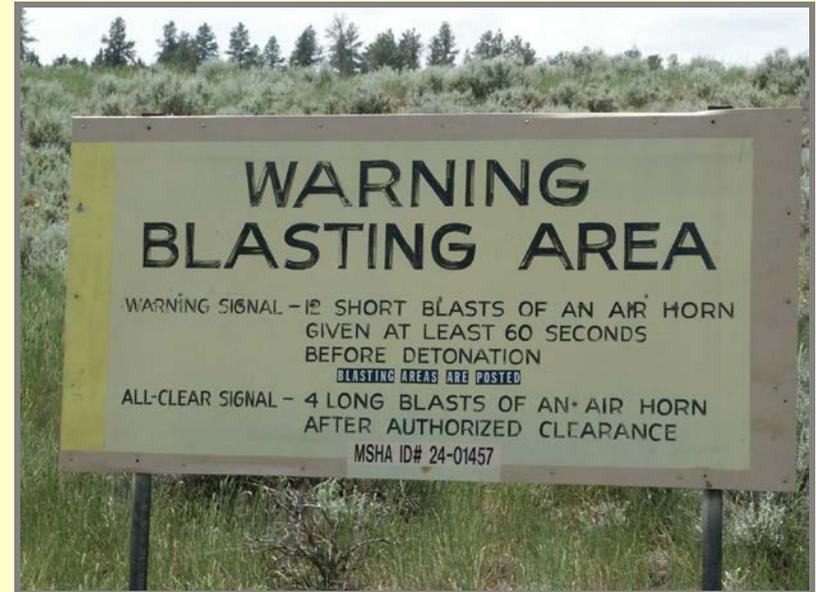
Unscheduled, “emergency” blasts may take place as long as the reason is documented and residents within 1/2 mile are notified with audible signals.

	April 21, 2000
TO:	Resident
FROM:	Dog Run Coal Company 16 Maple Lane McMurray, PA 16223 (412) 937- 2910
SUBJECT:	Blasting Schedule Notification Powderly Mine, Permit #9412815 South Fayette Township, Alleghany County, PA
Dog Run Coal Company plans to start the Powderly mine on or about May 1, 2000. The project will involve blasting of rock to mine the Pittsburgh coalbed. Blasting over the next year will occur along Bise Ridge adjacent to State Route 23.	
Blasting will occur during daylight hours and according to the following schedule:	
Monday through Saturday	9 AM to 5 PM
Sunday.....	No blasting
Prior to each blast, a warning signal, audible to 1/2-mile, will be sounded and all access roads to the mine will be blocked by mine personnel. The warnings will be:	
Three 10-second tones.....	5 minutes until the blast
One 20-second tone.....	1 minute until the blast
Once the blaster has checked the blast site and determines the area to be safe, an all-clear signal will be sounded. The all-clear signal will be three 5 second tones.	
If you have any questions about this schedule, please contact us at the above address.	
May Done Mine Superintendent	

Performance Standards - Blasting Signs

30 CFR 816.66(a) - Blasting Signs

Blasting signs reading “**Blasting Area**” are to be conspicuously placed along the edge of any blasting area that comes within 100 feet of any public road right-of-way, as well as at the point where any other road provides access to the blasting area.



Signs that state “**Warning! Explosives in Use**” must also be placed at all entrances, from public roads or highways, to the permit area. Such signs must both clearly list and describe the meaning of the audible blast warning and all-clear signals that are in use and explain the markings of blasting areas and charged holes awaiting firing within the permit area.

Performance Standards - Audible Warnings



30 CFR 816.66(b) - Warnings

Warning and all-clear signals of different character or pattern that are audible within a range of 1/2 mile from the point of the blast shall be given.

Each person within the permit area and each person who resides or regularly works within 1/2 mile of the permit area shall be notified of the meaning of the signals in the blasting schedule.

Performance Standards - Access Control

30 CFR 816.66(c) – Access Control

Access within the blasting area shall be controlled to prevent presence of livestock or unauthorized persons during blasting.

Access will remain controlled until an authorized representative of the operator has reasonably determined that :

- no unusual hazards, such as imminent slides or undetonated charges, exist, and
- access to and travel within the blasting area can be safely resumed.

Typically the blaster is responsible for defining the blast area and the mine operator is responsible for securing the area.



Part II: Review Questions and Discussion

Describe the following warning signs at your mine, quarry, or blasting operation:

1. The pattern of audible warning signals or sirens sounded before blasting, as well as the all-clear signals or sirens sounded following a blast.
2. Signs used to control access to a blast site.
3. The markings used to outline loaded holes waiting to be fired.

Part II: Answers

1. Your answer should take into account the fact that both the character and the pattern of warning signals will differ from those of all-clear signals. All signals should be audible within a range of 1/2 mile from the point of a blast.
2. Your answer should take into account the following considerations: blasting signs reading “**Blasting Area**” should be conspicuously placed along the edge of any blasting area that comes within 100 feet of any public road right-of-way, as well as at the point where any other road provides access to the blasting area. Signs that state “**Warning! Explosives in Use**” must also be placed at all entrances, from public roads or highways, to a permit area in which blasting occurs. Such signs must both clearly list and describe the meaning of the audible blast warning and all-clear signals that are in use and explain the markings of blasting areas and charged holes awaiting firing within the permit area.
3. Often, blast patterns will be loaded with yellow and red cones and marked with warnings signs. Your answer should include a similar approach.

Part III: Performance Standards – Adverse Effects

CONTROLLING the ADVERSE EFFECTS of BLASTING - 30 CFR 816.67

Blasting shall be conducted to prevent injury to persons, damage to property, underground mines and water supplies outside the permit area.

To this end, blasting performance standards are applied to control ground vibrations, airblast, and flyrock. Ground vibration and airblast limits focus on preventing damage to structures outside the permit area. Blast area security is the focus of preventing injury from flyrock, concussion and fumes.

The vibration limits should not be exceeded at any dwelling, public building, school, church, community building or institutional building outside the permit area (except mine owned buildings).

Vibration limits at other man-made structure need to be specified in the blast plan

If necessary, to ensure damage prevention, the RA may set lower limits in the blast plan and require monitoring of any or all blasts and may specify the location of the monitoring.

Airblast Limits – 30 CFR 816.67(b)

The airblast limits at any man-made structure shall not exceed the levels specified in the table below. The operator shall conduct periodic monitoring to ensure compliance, but is subject to modification by the RA.

Airblast Limits - The monitoring system will have an upper-end flat frequency response of at least 200 Hz

Lower frequency limit of measuring system (in Hz)	Maximum level (in ± 3 dB)
0.1 Hz or lower ¹	134 peak
2 Hz or lower	133 peak²
6 Hz or lower	128 peak
C-weighted ^{1,3}	105 dBC

¹Only when approved by the regulatory authority.

²**Blasting seismographs used today have a lower-end, flat-frequency response of 2 Hz; therefore, the airblast limit is normally set at 133 dB.**

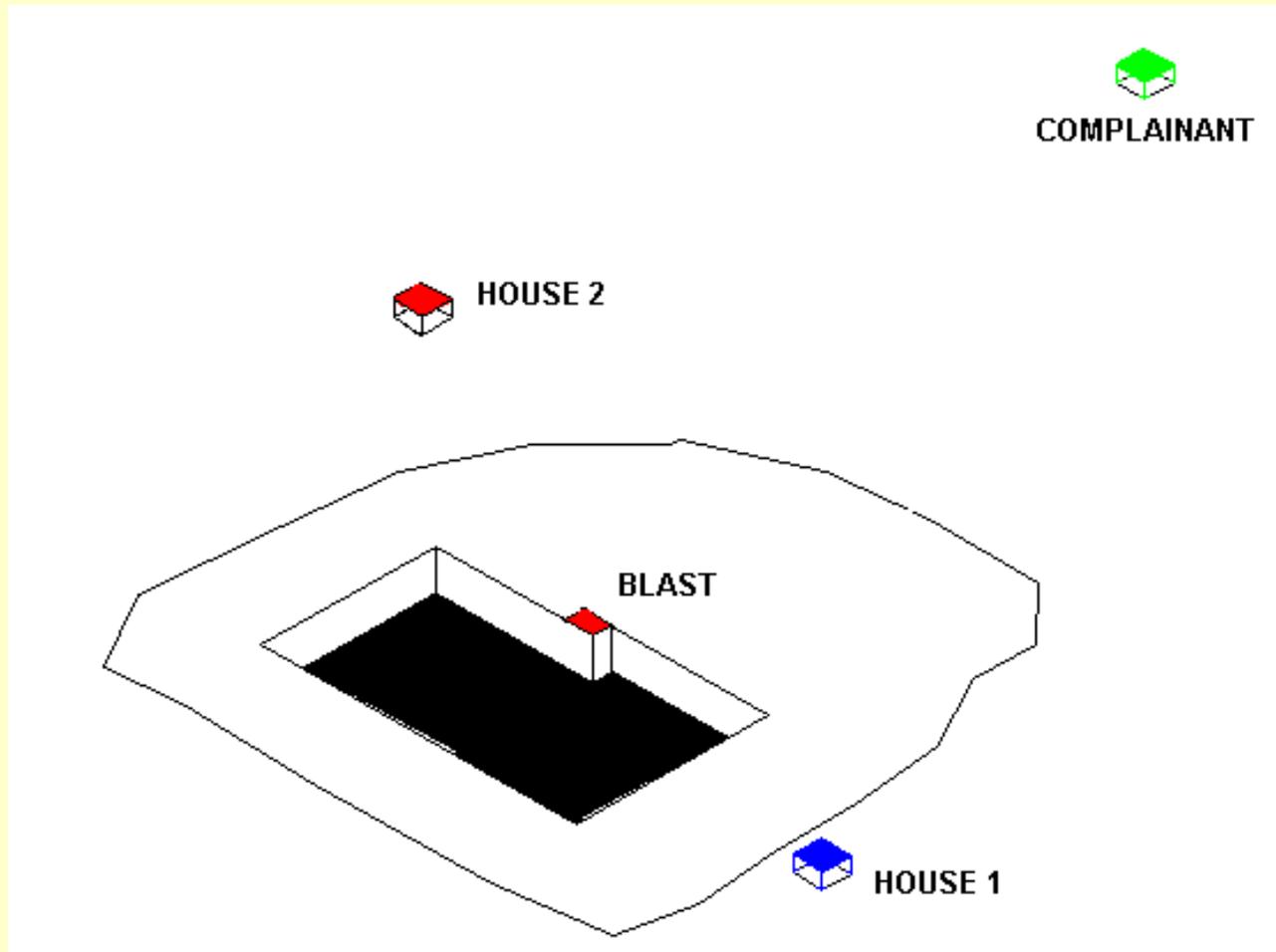
³A “C-weighted” system misses the middle and high frequency levels.

All blasting seismographs currently manufactured have a frequency range from 2 – 250 Hertz.

Airblast

Example 1:

What is the airblast limit at the green house site pictured below if the lower frequency response range of the microphone is 2 Hz?



Airblast

Answer 1:

The regulatory limit for any blast monitored with a 2 Hz microphone, at any house, is 133 dB.

Flyrock – 30 CFR 816.67(c)

Flyrock traveling in the air or along the ground shall not be cast from a blasting site:

- More than one-half the distance to the nearest dwelling or other occupied structure,
- Beyond the “area of control” (that is, the blasting area), or
- Beyond the permit boundary.

The regulatory limit, in the case of flyrock, is taken to be the shortest of the distances measured in accordance with these three restrictions.

Material cast on the down slope



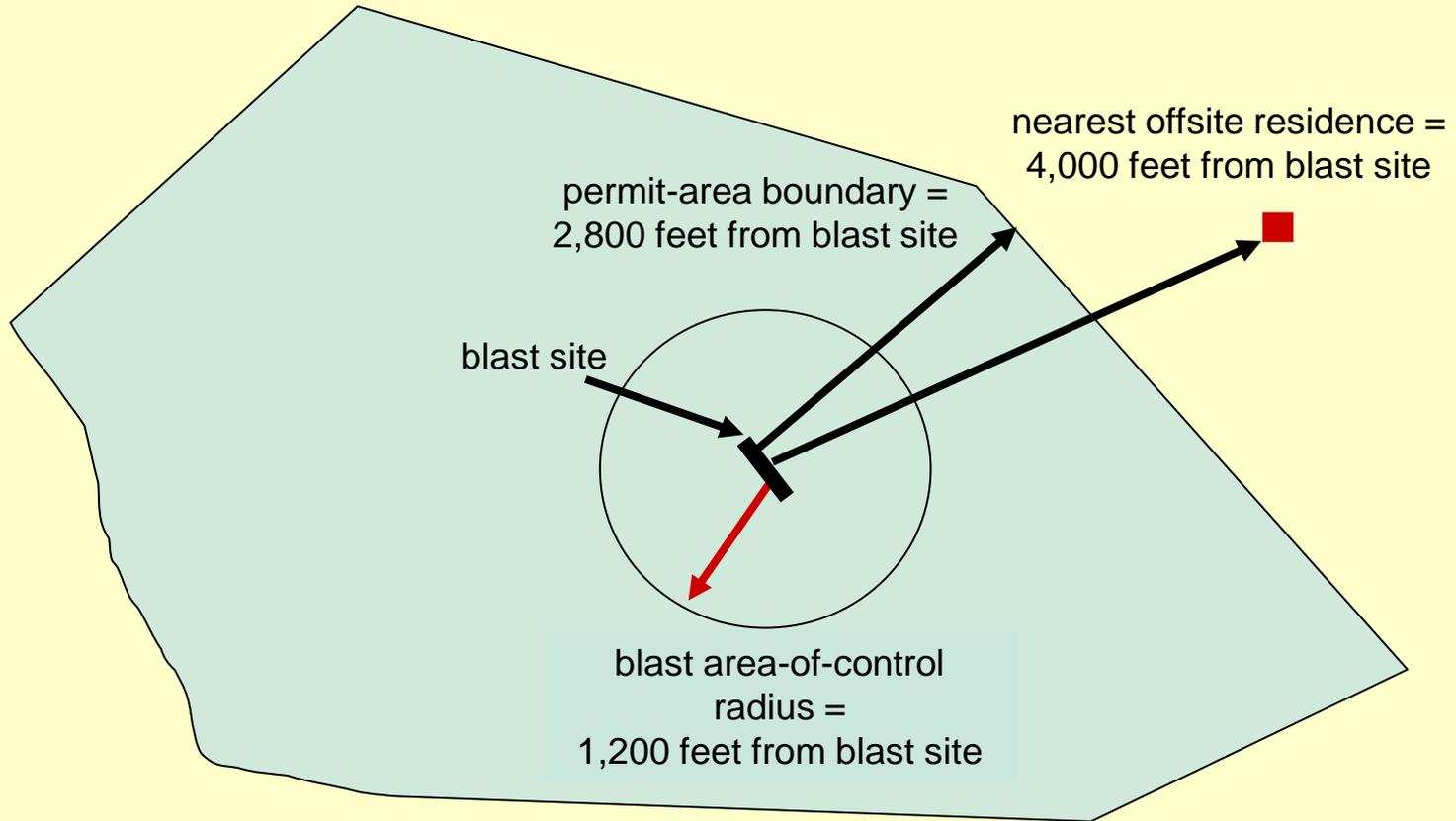
Flyrock at a steep slope site



Flyrock

Example 2:

What is the limit to flyrock throw for the blast site pictured below?



Flyrock

Answer 2:

Calculations related to this example and derived from the three relevant restrictions to flyrock cast would be:

One-half the distance to the closest home = $4,000 \text{ feet} / 2 = 2,000 \text{ feet}$

Permit-area boundary limitation = 2,800 feet

Area of control surrounding the blast site = 1,200 feet

Because the regulatory limit for any given blast is the shortest distance measured in accordance with these restrictions, the correct answer would be 1,200 feet. No flyrock may be thrown beyond 1,200 feet from the blast.

Ground Vibration Limits – 30 CFR 186.67(d)

Performance standards state that the maximum ground vibrations shall not exceed values approved in the blasting plan.

Four different options are available to show compliance. All but one option requires that blasting seismographs are used to show evidence of compliance.

Option 1.—Use table 1 to determine the maximum allowable PPV for ground vibration. The PPV is set to specific values based on the distance from a given blast to the closest offsite structure. The use of a seismograph is required to show compliance.

Option 2.—Use the scaled-distance value in table 2 to determine the maximum allowable charge weight of explosives that can be detonated within any 8 milliseconds delay interval. A seismograph is not needed to show compliance.

Option 3.—Use the modified blasting-level chart pictured in figure 1 to determine the maximum allowable PPV as a function of predominate frequency at the PPV. The use of a seismograph is required to show compliance.

Option 4.—Use a modified scaled distance determined by site specific vibration data. The methodology must be approved by the RA. The use of a blasting seismograph is initially required but not after the scaled distance is modified.

Ground-Vibration Limits - PPV

- Ground vibration frequencies tend to decrease with increasing distance from a blast.
- This three tier approach requires lower PPV limits as the frequency decreases.
- A blasting seismograph must be used.

Table 1.—*Maximum allowable PPV*

Distance from the blasting site (feet)	Maximum allowable PPV for ground vibration (ips) ¹
0 to 300	1.25
301 to 5,000	1.00
5,001 and beyond	0.75

¹Ground vibration shall be measured as the particle velocity. Particle velocity shall be recorded in three mutually perpendicular directions (R, V, and T), and the maximum allowable PPV shall apply to measurements for each.

Ground-Vibration Limits: Scaled Distance

- Ground vibration frequencies tend to decrease with increasing distance from a blast.
- This three tier approach requires higher limits as the frequency decreases.
- A blasting seismograph is not required.

Table 2.—*Scaled-distance factors*

Distance from the blasting site (feet)	Scaled-distance factors (Ds)
0 to 300	50
301 to 5,000	55
5,001 and beyond	65

Scaled distance for a given blast is calculated as:

$$Ds = \frac{D}{\sqrt{W}}$$

where D = distance from the blast site to the nearest offsite structure and W = maximum charge weight of explosives in pounds detonated within any 8-millisecond delay interval

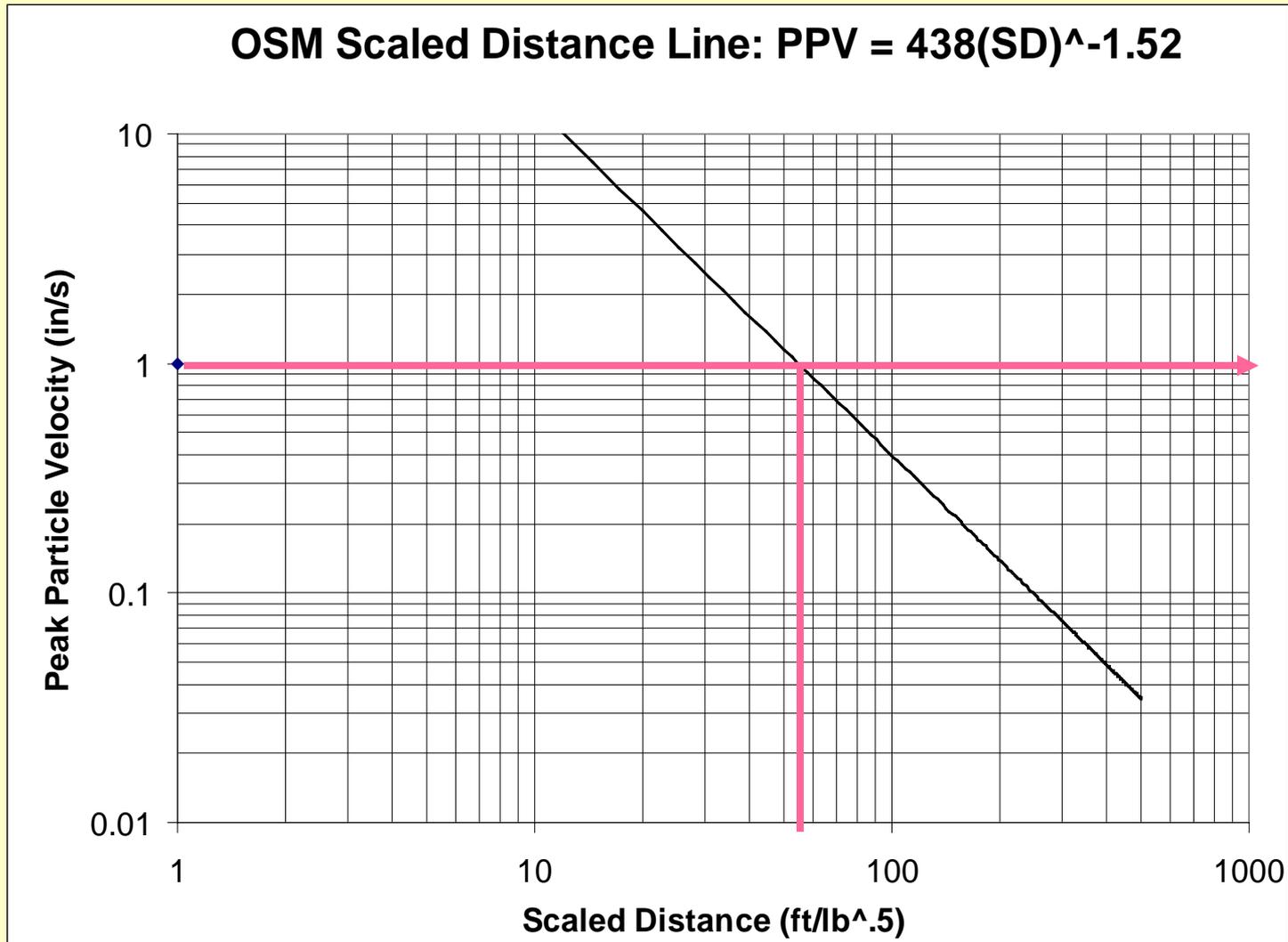
For a given scaled-distance factor, the allowable charge weight per 8-ms delay, W, can be calculated from the distance to the closest structure:

$$W = \left(\frac{D}{Ds} \right)^2$$

Knowing the distance, D, to the nearest structure, the Ds value can be selected from table 2 and used in the equation above to calculate W.

OSM – SD/PPV Relationship, Coal Mines

The PPV limitations of Table 1 and the scaled distance limitations of Table 2 for each distance range are tied together with the following equation and is illustrated on the graph. If a scaled distance of 55 is entered into the equation, the resultant PPV is 0.99 ips. Similar value result from the other scaled distances



Ground-Vibration Limits: Modified Blasting Level Chart

The solid black line forming the “Z” in figure 1 represents the upper limit to “safe” ground vibrations produced by a blast. To meet this definition, vibrations must be measured at the structure using a seismograph.

The PV and associated frequency are plotted within figure 1. If a given ground-vibration data point falls *below* the solid black line, that vibration is in compliance.

Put another way, data that plot *below* the line are considered to be within the safe zone. Data that fall *above* the solid line are considered unsafe and may cause cracking in structures.

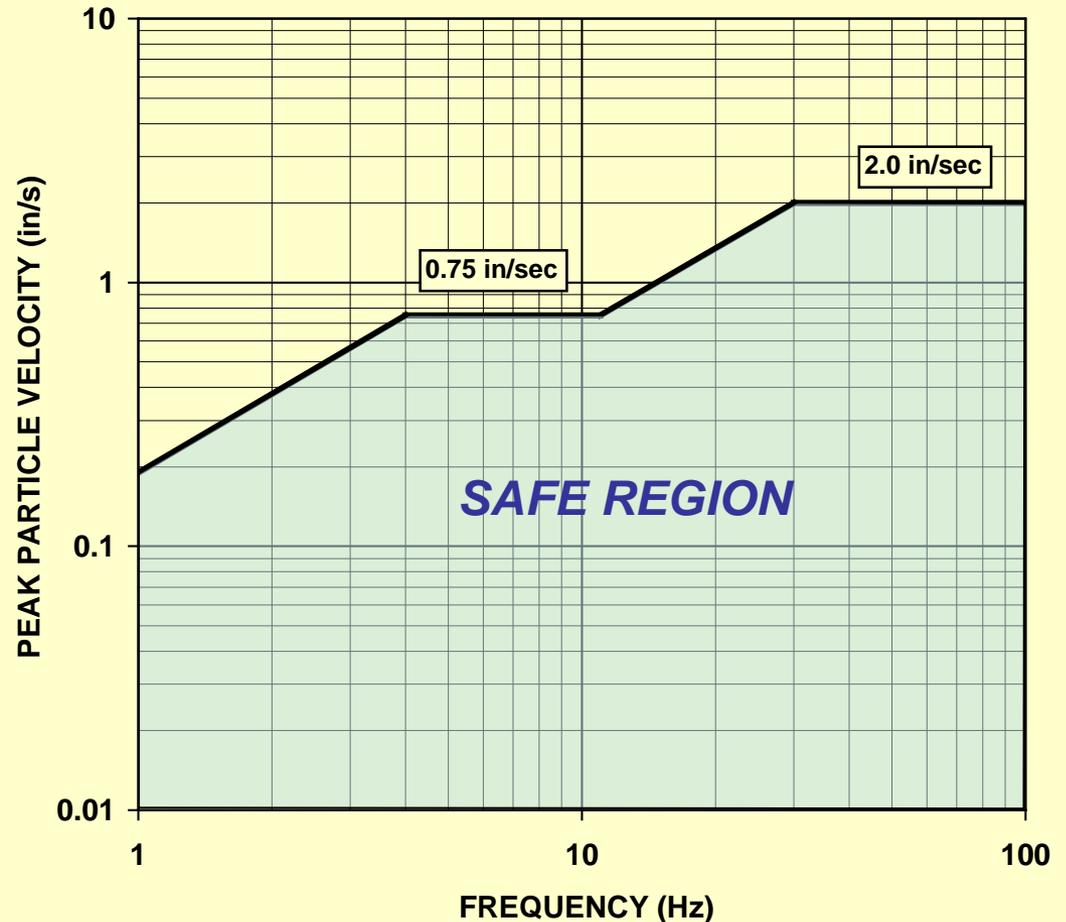


Figure 1.—Modified Blasting Level Chart

Ground-Vibration Limits: Modified Ds Factor

If the blasting parameters under the scaled distance option are too restrictive, an operator may choose to develop a modified scaled distance. Under this option, the mine operator establishes a site-specific Ds factor by plotting site-specific scaled distance vs peak particle velocity data and performing a regression analysis.

This is done by placing seismographs at varying distances from the blast, compiling data for the PPV and frequency at the peak, and computing the actual scaled distance at each seismograph.

For example,

$$D_s = \frac{D}{\sqrt{W}} \quad \text{where} \quad \begin{array}{l} D = \text{the distance between the seismograph and the blast and} \\ W = \text{maximum charge weight per 8-millisecond delay.} \end{array}$$

Once scaled distance is plotted against PPV on log-log paper a regression analysis will determine the A “best-fit” line of the data set. Then if an adequate correlation coefficient ($r^2 > 0.70$) exists, scaled distance can be used as a reliable predictor of PPV. Based on the statistics, two standard deviations from the mean will result in a line that encompasses 95 percent of the data points. This line will plot parallel to and above the “best-fit” line.

Using the 95 percent confidence line, the PPV limit to which the mine must comply is selected from table 1. A horizontal line is made on the plot from the PPV values of 0.75, 1.00 and 1.25 over to the 95 percentile line. The value of these intersections, projected on the x-axis, will give a Ds value at the various distance of 0-300, 301 to 5000 and >5,000 feet that may be used for blast design.

The new *Ds factors is considered less restrictive* if they are lower than the corresponding value shown in table 2.

Ground-Vibration Limits: PPV Example

Example 3: A private residence is 780 feet from a planned blast. According to table 1 (which is used under option 1 to determine the maximum allowable PPV for ground vibration), what is the maximum PPV allowed at the residence?

Answer 3: In this example, $D = 780$ feet falls within the range of 301 to 5,000 feet. Table 1 shows the maximum allowable PPV for this range to be 1.00 ips in any one of the mutually perpendicular directions of R, V, or T.

Note that compliance using table 1 must be verified by measuring vibrations with a blasting seismograph at structures affected by blasting.

Ground-Vibration Limits: Scaled Distance Example

Example 4: Let's say that you don't want to use a blasting seismograph to monitor vibrations at a blast site. A structure exists 800 feet from the blast site. What is the maximum charge weight, W (lbs/delay), that can be detonated within 8 milliseconds?

Answer 4: In this example, $D = 800$ feet. According to table 2 (which is used under option 2 to determine the maximum allowable quantity of explosive charge that can be detonated within any 8-millisecond delay interval), 800 feet is within the range of 301 to 5,000 feet. Table 2 shows the D_s factor for this range to be 55. Thus,

$$W = \left(\frac{D}{D_s} \right)^2 = \left(\frac{800}{55} \right)^2 = (14.5)^2 = 211 \text{ lbs / delay.}$$

Always round down your calculations.

Ground-Vibration Limits: Scaled Distance Example

Example 5: Assume now that a structure resides 10,000 feet from a blast site. What is the maximum pounds per delay that can be used at the site?

Answer 5: According to table 2, if $D = 10,000$ feet, the D_s factor is 65. Therefore,

$$W = \left(\frac{D}{D_s} \right)^2 = \left(\frac{10,000}{65} \right)^2 = (153.84)^2 = 23,668 \text{ lbs / delay.}$$

Ground-Vibration Limits: Blasting Level Chart Example

Example 6: Under option 3, a Z-curve, or blasting-level chart, can be used to determine the maximum allowable PPV as a function of predominate frequency at the PPV. Under this option, the use of a seismograph is required to show compliance.

Use the blasting level chart on the next slide to locate and plot the following seismographic measurements, which data taken from a home:

PPV (ips)	Frequency at the PPV (Hz)
0.35	22
0.09	4
1.40	58
0.90	10

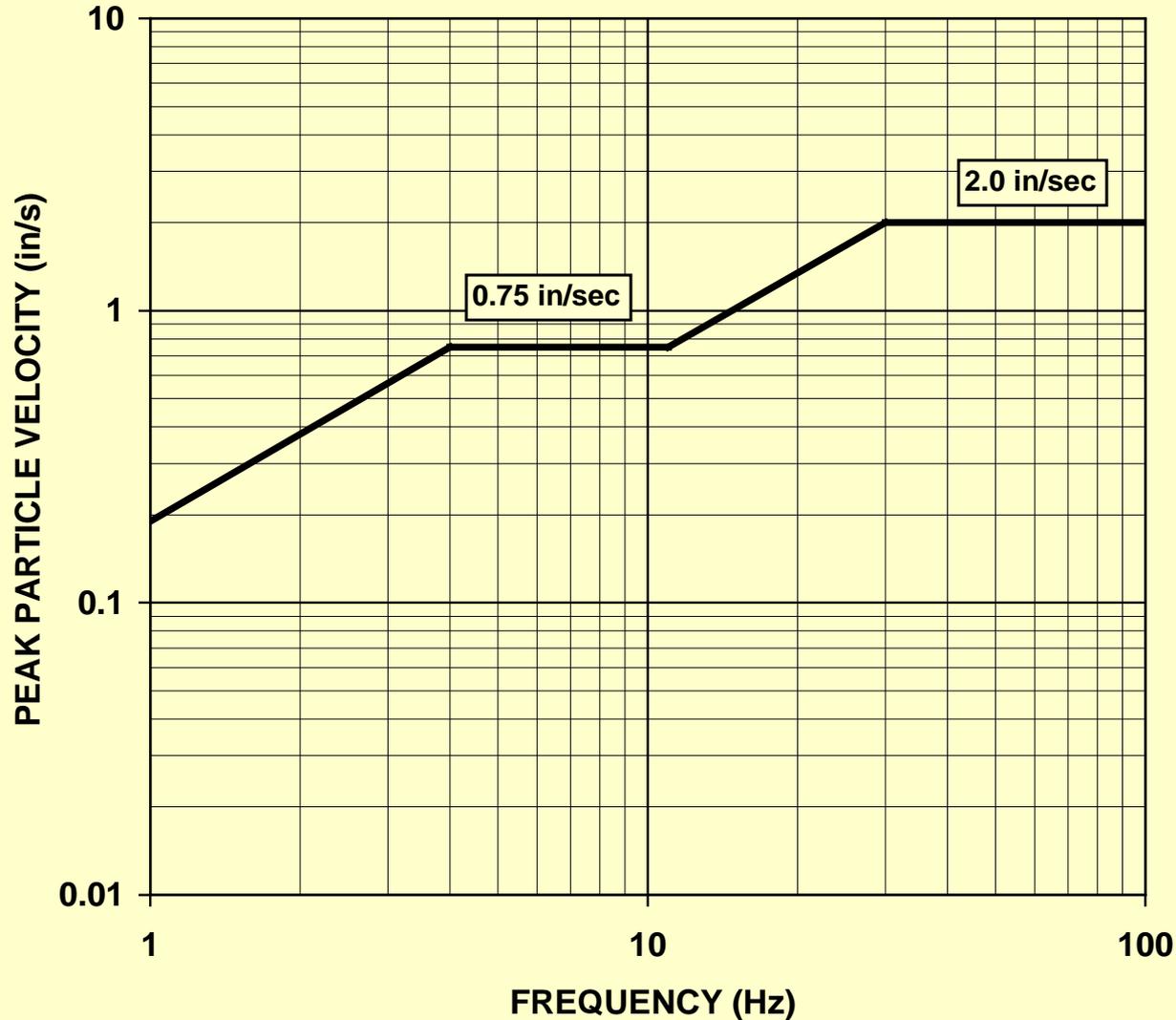
Which of these data, if any, is out of compliance?

Instructions:

If you have a printer attached to your computer, go to the next slide and exit the slide show (use the “Esc” button). Print the slide and plot the seismographic-measurement data by finding the PPV values on the y-axis of the graph and the frequency on the x-axis. Go to the following slide to find the answers.

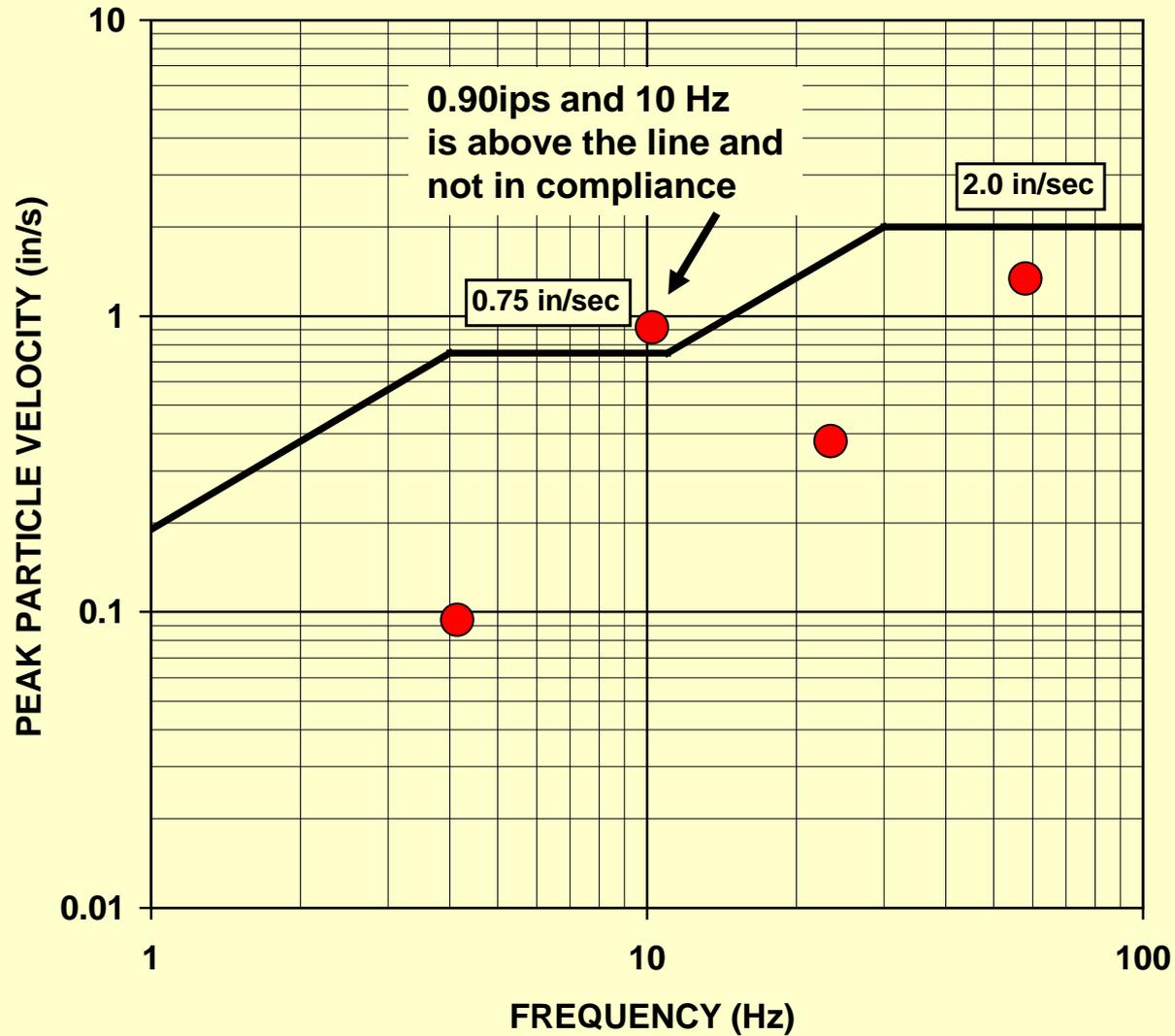
Ground-Vibration Limits: Blasting Level Chart Example

To print this page, once you “Esc” the slide show, click File and then Print. Select Current Slide. Click OK.



Ground-Vibration Limits: Blasting Level Chart Example

Answer 6:



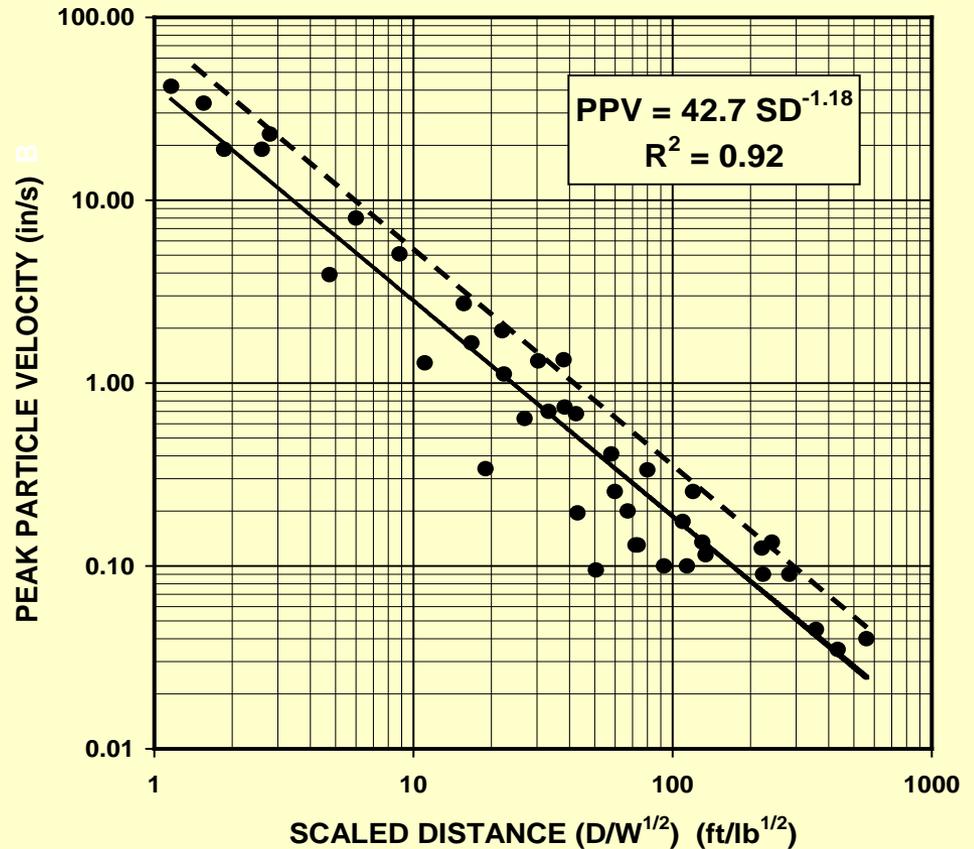
Ground-Vibration Limits: Modified Scaled Distance

Example 7:

Remember that a modified scaled distance should yield less restrictive scaled distance values based on vibration monitoring.

Say that forty seismograph readings have been taken at a quarry. These readings are plotted on the graph to the right as PPV versus D_s . Regression analysis yields the “best-fit” solid line, that is represented by the equation. The dashed line represents two standard deviations from the mean, below which 95 percent of all data fall. An R^2 means that for the data gathered, scaled distance is an excellent predictor of PPV (minimum value of 0.70).

Assume that a structure exists at 800 feet from the blast site. The Peak Particle Velocity allowable at this distance is 1.0 ips (table 1). Under the scaled distance limitations of table 2 at 800 feet the D_s is 55. Thus the allowable charge weight is computed to be 211 lbs/delay.



Ground-Vibration Limits: Option 4

Answer 7:

To determine the modified scaled distance use the 95 percent confidence line.

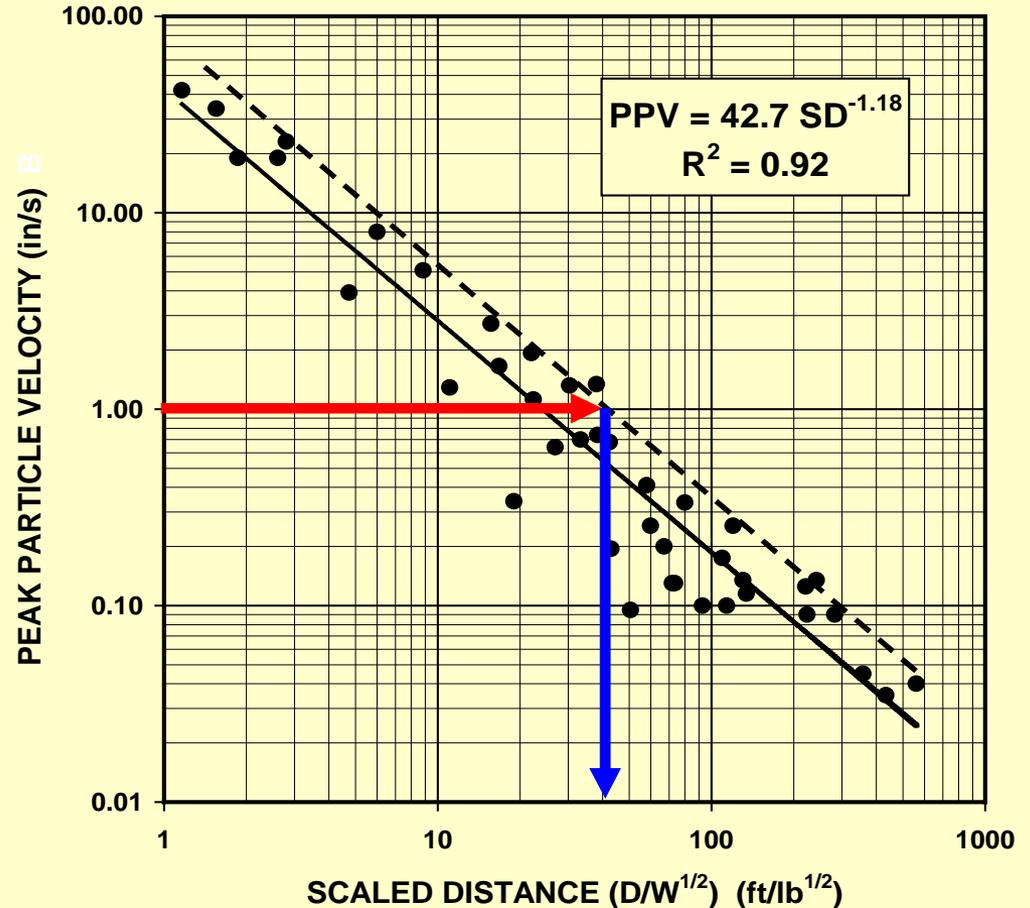
With 1.00 ips as the maximum vibration limit, a horizontal line can be made on the graph to the right from the 1.00 mark on the y-axis to the dashed line (shown in red).

From the intersection with the dashed line, a vertical line is drawn (in blue) to determine the D_s value that could be used to ensure—with 95-percent confidence—a PPV of 1.00 ips or less. The revised scaled distance value is 40:

Rather than being limited to 211 lbs/delay, W can now be increased by using a lower D_s factor such that:

$$W = \left(\frac{D}{D_s} \right)^2 = \left(\frac{800}{40} \right)^2 = (20)^2 = 400 \text{ lbs / delay}$$

The procedure used to exercise option 4 may vary among regions or States. The local regulatory authority must approve site-specific D_s factors that will ensure compliance with safe vibration limits.



Blast Records

Company use of Blast Records

- Regulatory requirement – show compliance
- Post blast assessment - analyzing problems
- Liability protection - Documentation or Evidence of the actual blast pattern used



Regulatory use of Blast Records

- Evaluate Competence of Blaster
 - Following acceptable blasting practices
- Determine if blasting operations may pose an Imminent Danger
- Post blast assessment of flyrock
- Address annoyance complaints
- Address damage allegations

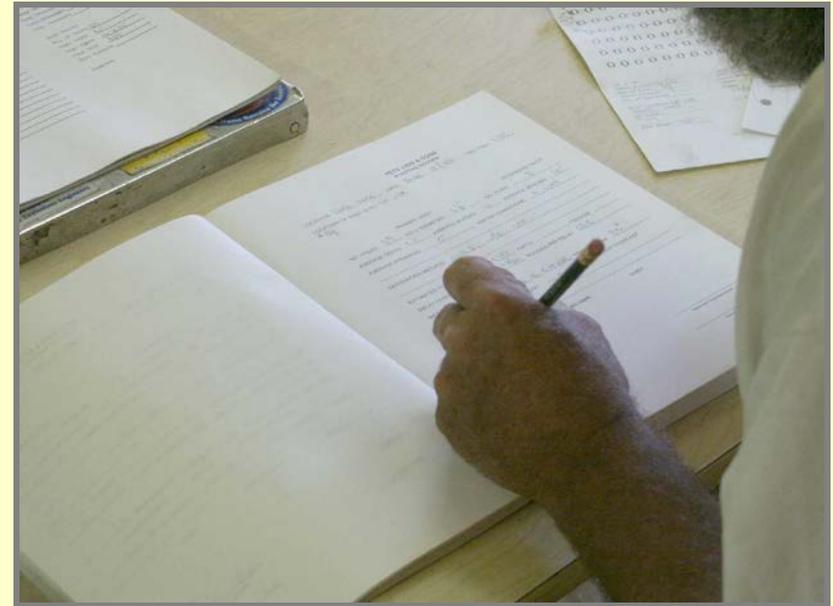
Records of Blasting Operations – 30 CFR 816.68

An operator shall retain a record of every blast within its permit-area boundary for at least **3 years** following the blast.

Upon request, copies of these records shall be made available to the regulatory authority and to the public for inspection.

Such records shall contain the following data:

1. Name of the operator conducting the blast;
2. Location, date, and time of the blast;
3. Name, signature, and certification number of the blaster conducting the blast;
4. Identification of the nearest dwelling, public building, school, church, community, or institutional building outside the permit area, as well as the direction and distance in feet from the nearest blasthole to the nearest structure;
5. Weather conditions at the time of the blast, including conditions that might have caused possible adverse blasting effects;
6. Type of material blasted;

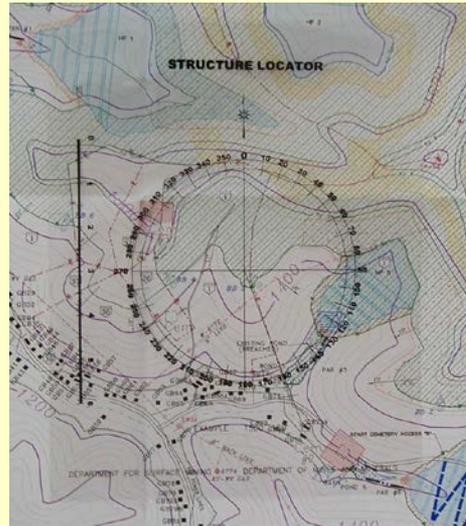


Records of Blasting Operations—continued



7. Sketches of the blast pattern, including number of holes, burden, spacing, decks, and delay pattern;
8. The diameter and depth of holes;
9. Types of explosives used;
10. Total weight of explosives used per hole;
11. The maximum weight of explosives detonated in an 8-millisecond period;
12. A description of the initiation system;
13. A description of the type and length of stemming;
14. Mats or other protections used;
15. Seismographic and airblast records, if required, which shall specify (a) the type of instrument, its sensitivity, and the calibration signal or certification of annual calibration; (b) the exact location of the instrument, the distance from the blast of its placement, and the dates and times of each of its records; (c) name of the person and firm taking the reading; (d) the name of the person and the firm analyzing the seismographic record; and (e) the vibration and/or airblast level recorded; and
16. The reasons and conditions for each unscheduled blast.

Records of Blasting Operations – Blast Location



Locate the blast site within the permit boundary

Two components

- Latitude and Longitude
- Northing and Easting
- Distance and Direction

How?

- Survey
- Compass and tape or range finder
- GPS - Global Positioning System



Best Technology Currently Available - GPS Locations

- Latitude-Longitude
- UTM
- Convert to state plane coordinates if needed

Note Projection System

WGS 84

NAD 27

Big Blasts – 4 corners or tracks

Accuracy +/- 10 feet

Records of Blasting Operations – Identify Nearest Structure



Identify the correct structure

- Street Address
- Full name of occupant
- House number from permit map
- Verify that the structure exists



Distance and Direction

Distance from the closest blast hole

Cardinal directions are too general

Azimuth to the structure (1500 feet 160 degrees)

Distance: two significant digits

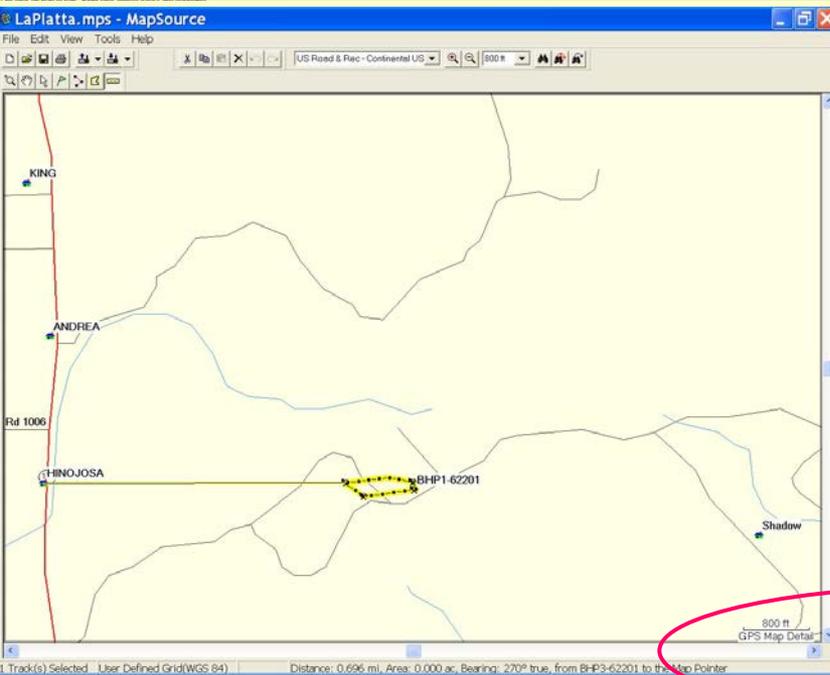
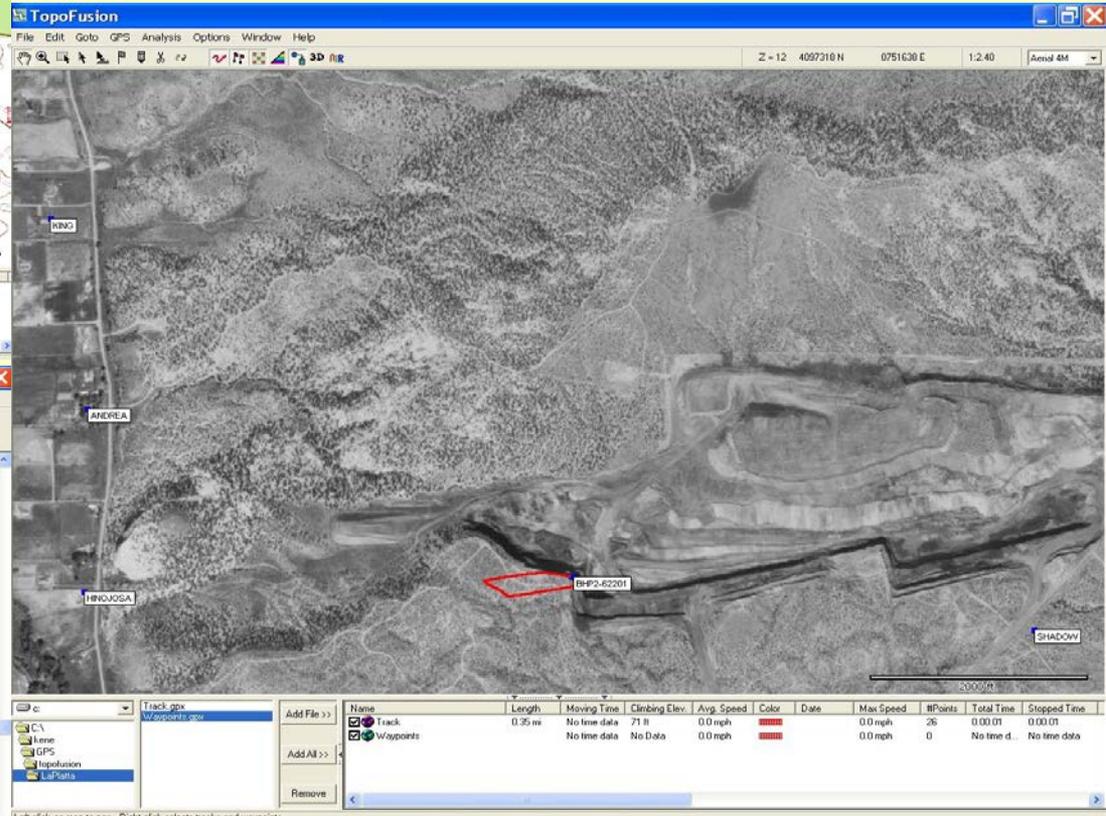
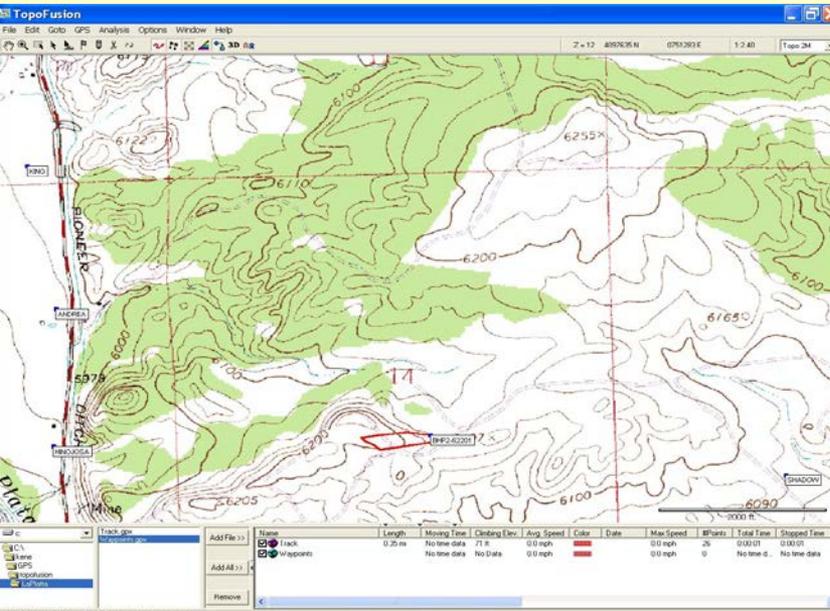
< 100'to the nearest foot

100' – 1,000'to the nearest 10 feet

1000' – 10,000' ...to the nearest 100 feet

Records of Blasting Operations – Spatial Relationships

GPS example, track the perimeter of the blast with waypoints at the four corner. Nearby houses shown



Distance: 0.696 mi, Area: 0.000 ac, Bearing: 270° true, from BHP3-62201 to the Map Pointer



Records of Blasting Operations – Distances with Coordinates

Pythagorean Theorem: serves as a basis for the definition of distance between two points.

$$a^2 + b^2 = c^2$$

With State plane or UTM coordinates:

$$D = \sqrt{(E_1 - E_2)^2 + (N_1 - N_2)^2}$$

D – distance, E – easting, N - northing

Records of Blasting Operations – Weight of Explosives per Hole

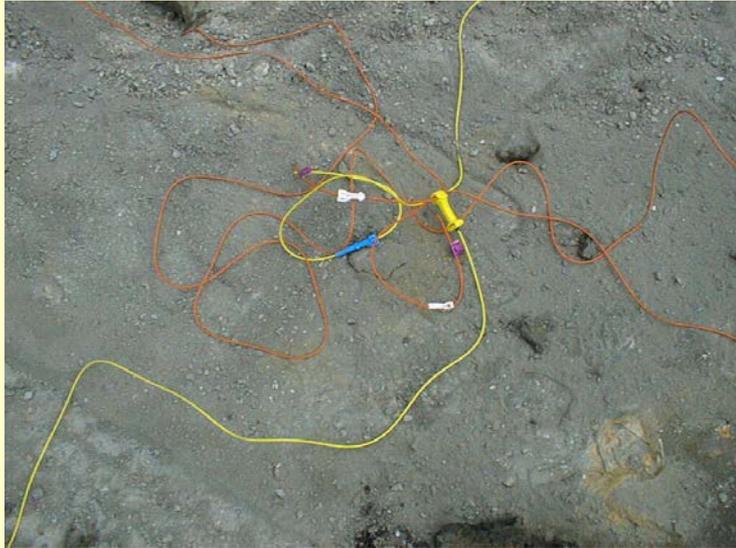
The weight of explosives in each hole is required by SMCRA and is needed to determine the powder distribution in the pattern. Most important for flyrock control and post blast assessment of performance.

- Not the average!
- All holes may be loaded the same
- Powder distribution is critical for post blast assessment
- Steep slopes critical w/ hole depths variations





Records of Blasting Operations – Charge Weight per Delay



Time the Blast!

- Surface MS times
- Downhole MS times
- Look for overlaps
- Report the maximum value w/in 8-ms
- Critical vibration control entry

Time each blast out until you are comfortable with the sequencing of the pattern. Take a real close look at decked patterns.

With electric blasting the cap's identification numbers are listed, with no note on the millisecond delay time. If a sequential blasting machine is used, the record may show the same cap numbers for each row with a board time, the number of milliseconds delay between circuits. Obtain the manufacturer's product specification sheet if needed.

In the Non-electric world, each cap has the delay detonator times. It is critical to time out a few shots in order to understand how the blaster calculates the pattern times.

When all down hole delay times are identical, only the surface delay times need to be calculated to determine the holes per *millisecond delay period. Decking shots are most challenging for overlaps, time these patterns out.

Part III: Review Questions and Discussion

1. A residential structure is located 3,500 feet from a blast site. Each blasthole is loaded with 2,000 pounds of explosives. How many holes can be detonated within 8 milliseconds?
2. A church is located 280 feet from a mine road cut that will be blasted. How many pounds can be detonated per delay in the blast?
3. A blasting operator must offer a pre-blast survey to all non-mine-owned structures between the permit-area boundary and up to how many miles away?
4. List three things that must be posted on signs at entrances to a mining permit area that is conducting blasting from all public roads and highways.
5. True or false: airblast does not need to be monitored, but ground vibrations must always be monitored using a blasting seismograph.
6. True or false: blasting records must be kept on file at a mine for 5 years.
7. Blasting schedules published in local newspapers and distributed to utility owners, local governments and residents within 1/2 mile of a permit area proposing blasting must include what information?
8. Blasting signs reading "**Blasting Area**" are to be conspicuously placed along the edge of any blasting area within how many feet of any public-road right-of-way?

Part III: Review Questions and Discussion—continued

9. Particle velocity measures the speed of :
 - a. Flyrock
 - b. Detonation cord
 - c. Ground movement caused by a blast
 - d. The velocity of an explosive detonation

10. Copies of pre-blast surveys shall be promptly provided to:
 - a. The Department of Alcohol, Tobacco, Firearms and Explosives
 - b. The Governor of the State in which the blasting will occur
 - c. The State or Federal regulatory authority and the person requesting the survey
 - d. None of the above

11. Blasting schedules must be republished and redistributed at least every:
 - a. 3 months
 - b. 2 years
 - c. 6 months
 - d. 12 months

12. When setting up a seismograph to monitor blasting vibrations at a residence, it is best to keep the geophone:
 - a. In the center of the living room floor
 - b. Buried firmly in the ground outside the structure
 - c. On the inside of a window ledge
 - d. Unplugged

Part III: Answers

1. According to table 2, if $D = 3,500$ feet, $D_s = 55$. Solving for W ,

$$W = \left(\frac{D}{D_s} \right)^2 = \left(\frac{3,500}{55} \right)^2 = 4,049 \text{ lbs / delay}$$

The limit 4,049 lbs/delay \approx 4,000 lbs/delay. Given that each blasthole is loaded with 2,000 pounds of explosives, two holes detonating at one time (2,000 lbs/hole x two holes) would meet this limit. Thus, two holes detonated per 8-millisecond delay would be acceptable.

2. According to table 2, if D is less than 301 feet, $D_s = 50$. Solving for W as the nearest whole number rounding up,

$$W = \left(\frac{D}{D_s} \right)^2 = \left(\frac{280}{50} \right)^2 = 31.36 \text{ lbs / delay}$$

or 32 lbs/delay.

3. 1/2 mile
4. “Warning. Explosives in Use;” the audible warning patterns both for an impending blast and for the post-blast all-clear; and a description of barricades or markers that delineate the blast-site perimeter and all charged holes.

Part III: Answers—continued

5. False. Airblast must be periodically monitored with a blasting seismograph, whereas ground vibrations do not have to be monitored in cases where the blast has been designed using the scaled distance (Ds) formula.
6. False. Records must be kept for 3 years.
7. The name, address, and telephone number of operator; an identification of the specific areas in which blasting will take place; the dates and time periods when explosives are to be detonated; the methods to be used to control access to the blasting area; and the type and patterns of audible warning and all-clear signals to be used before and after blasting.
8. 100 feet
9. c. is correct.
10. c. is correct.
11. d. is correct.
12. b. is correct.